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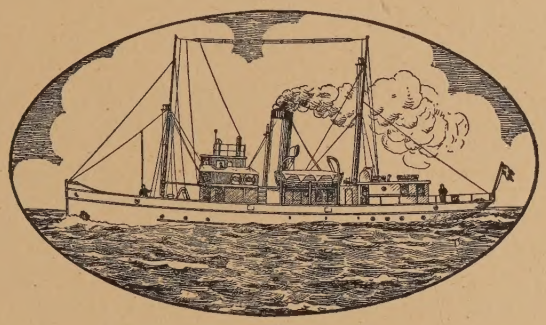
of

The Danish Biological Station

to

The Ministry of Agriculture and Fisheries



XLVI.

1941.

By

H. Blegvad, Ph. D.
Director

Copenhagen. C. A. Reitzel.
1944.

The Reports from the Danish Biological Station (Nos. I—XXI) are published in the official Danish "Fiskeri-Beretning" for the years 1890—91 until 1912. After this year they appear as special publications. The Reports I—XXXII are edited by Dr. C. G. Joh. Petersen, the Reports XXXIII—XXXVI by Dr. A. C. Johansen and the later Reports by Dr. H. Blegvad.

I. *C. G. Joh. Petersen:* Fiskenes biologiske Forhold i Holbæk Fjord. (1890—91)*) 63 pp. 1 Chart. Out of print.

II. *Idem:* On the Eggs and Breeding of our Gobiidæ. (1891—92.) 9 pp. Two Plates. Out of print.

III. *Idem:* The Pelagic Life in Fænø Sound etc. (1892—93.) 38 pp. Tables. Out of print.

IV. *Idem:* On the Biology of our Flat-fishes and on the decrease of our Flat-fish Fisheries. (1893—94.) 146 pp. 2 Plates. 1 Chart. Many Tables. Out of print.

V. *Idem:* The common Eel (*Anguilla vulgaris* T.) gets a Particular Breeding-dress before its Emigration to the Sea. (1894—95.) 35 pp. With 2 Plates.
Etc. 64 pp. Out of print.

VI. *Idem:* The Yearly Immigration of young Plaice into the Limfjord etc. (1895—96). 48 pp. 1 Chart. 2 Tables. Out of print.

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IX. *Idem:* Trawlings in the Skager Rack and the Northern Cattegat in 1897 and 98. 1899. 56 pp. With one Map. Out of print.

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XI. *Idem:* I. The Biology of the Cod in the Danish Seas. II. On other Codfishes in our Seas. III. Some General Observations on Protection, Legislation etc. IV. Alterations and Improvements on Otter-seines for Zoological Purposes. 1900 and 1901. 44 pp.

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XIII. *A. Otterstrøm:* Eggs and Young of Fishes in the Danish Waters. (Investigations during 1904 and earlier years.) 1903 and 1904. 85 pp.

XIV. I. *C. G. Joh. Petersen:* The Influence of Light on the Migrations of the Eel. II. *K. I. Gemzøe:* Age and Rate of Growth of the Eel. 1906. 39 pp.

XV. *Idem:* I. First Report on the Oysters and Oyster Fisheries in the Lim Fjord. (70 pp.) 1908.

XVI. *C. H. Ostenfeld:* On the Ecology and Distribution of the Grass Wrack (*Zostera marina*) in Danish Waters. With 9 figures. 1908. 62 pp.

XVII. *C. G. Joh. Petersen:* II. Second Report on the Oyster and Oyster Fisheries in the Lim Fjord. 1908. (24 pp).

XVIII. *C. G. Joh. Petersen:* I. The Yield of the Limfjord fisheries in recent years and the transplantation of Plaice in 1908. With 6 tables and 1 Chart. II. Biological investigations on the stock of Plaice in the Limfjord. With 3 Tables. III. The Yield of the Prawn fishery from 1885—1907 and its improvement by means of protection. With 3 Tables. 25 pp. 1909.

XIX. *Idem:* Some Experiments on the Possibility of combating the harmful Animals of the Fisheries, especially the Whelks in the Limfjord. 20 pp. 1911.

XX. *C. G. Joh. Petersen* og *P. Boysen Jensen:* Valuation of the Sea. I. Animal Life of the Sea-Bottom, its food and quantity. With 6 Tables, 3 Charts and 6 Plates. 81 pp. 1911.

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*) The figures in ( ) refer to the "Fiskeri-Beretning" for the years quoted.

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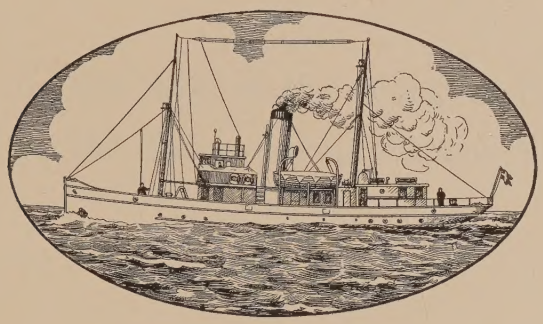

XLVI.

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Printed by Bianco Luno A/S, Copenhagen.

On Fluctuations in the Size of the Stock of Cod in the Waters within the Skaw during Recent Years.

By

ERIK M. POULSEN

CONTENTS

Page

Introduction 5
I. The annual fluctuations in the amount of fry 7
1. General remarks. Nature and extent of the material 7
2. The influence of temperature on the time at which the larvae appear 10
3. The frequency of the larvae in our different waters 10
4. The annual fluctuations in the amount of larvae 11
II. On the causes of the fluctuations in the amount of larvae 14
1. Fluctuations in the amount of cod eggs and the extent of the spawning 14
2. Salinity and temperature 18
3. The quantity of plankton 21
4. Survey 24
III. On the influence of the fluctuations in the amount of larvae on the size of the cod population 25
1. Fluctuations in the amount of growing-up cod 25
2. The connexion between fluctuations in the amount of larvae and growing-up cod 28
3. On the dependence of the catch yield on the amount of fry 29
IV. Fluctuations in the yield of the Danish cod fishery in 1920—40 31
1. Changes in the intensity and the methods of the fishery 31
2. Fluctuations in the size of the stock of cod and their dependence partly on the appearance of fry, partly on the fishery 32
Summary 35

Introduction.

Next to the plaice the cod is our most important fish. Everywhere in our waters—except in the deeper parts of the Skagerak and the inmost areas of our fjords—it plays a prominent part both in the fishery along the coast and in the open sea.

In the years 1937—40 the annual mean yields of the catches of our 7 most important fishes were as follows[1]) in tons and Danish Kroner:

	Plaice	Cod	Herring[2]	Mackerel	Eel[3]	Flounder	Dab
Tons.....	22 093	21 475	19 335	5 698	3 923	3 705	3 317
1000 Kr. .	17 011	5 775	5 120	1 647	5 584	1 584	1 159

In Figure 1 these figures are shown graphically. From the yield in quantity it appears that the landings of plaice, cod and herring are nearly equally heavy, each of them showing an amount of about 20 000 tons. From here there is a wide distance down to the next fish of the row, the mackerel, with a catch yield of barely 6 000 tons. Next come the fishes eel, flounder and dab with catch yields of nearly 4 000 tons. As far as the values of the yields are concerned the sequence of the species is different. Here the plaice is decidedly no. 1 with 17 mill. Kr., the species cod, eel and herring yielding only between 5 and 6 mill. Kr., while the last three species (mackerel, flounder and dab) range between 1 and 2 mill. Kr. In other words the plaice is no. 1 both in weight and value, the cod being no. 2 in both respects; in weight, however, the latter comes nearly as high as the former. The herring is no. 3 in weight, but only no. 4 in value, the eel here surpassing the herring on account of its comparatively greater value.

The importance of the cod in our fishery as compared to the two other of our most important fishes (plaice and herring) has been rising through these 30 years. Figure 2 represents the annual yields in tons of our three most important fisheries in four 4-years' periods between 1907 and 1940. It is noted

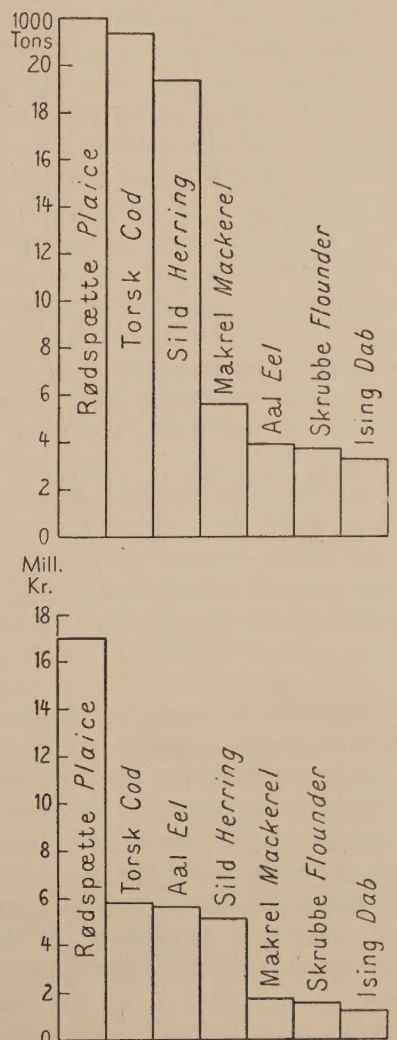

Figure 1. The annual mean yield in tons and Kroner of the fishery for our 7 most important fishes in the years 1937—40.

[1]) These and all other figures concerning yields of fishery in Danish Waters were taken from "Fiskeri-Beretningerne" (the Fishery-statistics), which are published by Fiskeridirektoratet (the Directorate of Fisheries).

[2]) Under "herring" are included sprat, but not such herring as are taken in the "waste fish" fishery.

[3]) Catches in salt water only.

that the weight yields of all three species have been rising rapidly through the years, the rise for the herring being about 40 per cent., for the plaice about 120 per cent. and for the cod no less than about 180 per cent., so that the cod shows by far the greatest rise within this period of years. It further appears from the figure that nearly the whole rise falls within the period 1907—30: during the last 10 years

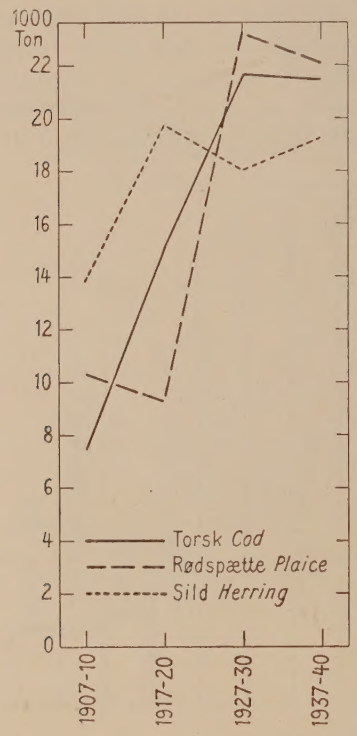

Figure 2. The annual mean yields in tons of the fisheries for cod, plaice and herring in four 4-years' periods between 1907 and 1940.

there has been no rise worth mentioning, the cod and plaice even showing a small decrease of weight.

As an important factor in our fisheries the cod has of course been the object of a number of investigations throughout the years, and together with plaice, herring and eel it belongs to our best-known fishes in a biological respect. In 1931[1]) I published some investigations on the biology of the cod in the Danish waters, principally based on a series of continuous observations from the years 1923—29. A branch of these investigations dealt with the great annual fluctuations in the amount of cod fry; the causes of these fluctuations were touched on together with their supposed effect on the amount of cod that is available to the fishery. The material originated from fishing experiments carried out partly by Kommissionen for Danmarks Fiskeri- og Havundersøgelser, partly by the Danish Biological Station down to the year 1929. Since then these fishing experiments in our waters have been carried on regularly by the Biological Station down to the outbreak of the second great war. On account of the temporary stopping of the fishing experiments since the autumn of 1939 I have considered it expedient to make another investigation into the fluctuations of the amount of fry and on their causes and importance, based on the total series of continuous investigations in hand from the 17-years' period of 1923—39.

The present investigation will include (1) an account of the annual fluctuations in the amount of cod larvae through our different waters, based on fishings with the ring-trawl for larvae in the spring months of 1923—39, (2) an account of the annual fluctuations in the amount of cod eggs, based on a material of weekly hauls with the Hensen net from the Anholt Knob, Schultz' Grund and Halskov Rev Light-vessels in the years 1930—41, (3) an examination into the cause of the found fluctuations in the amount of larvae, mainly based on a determination of the connexion between annual changes in certain hydrographical factors (temperature and salinity of the sea-water) and (4) an examination of the degree to which the quantity of growing-up cod (1, 2 and 3 years old) depends on the amount of larvae, in other words the degree to which the yield of the cod fishery depends on the amount of larvae; this will be examined by comparing the amount of larvae in spring with (1) the amount of brood of the bottom stage (0-Gr.) in the same summer, (2) the amount of little more than 1-year-old cod (I-Gr.) in the next year, (3) of 2-year-old cod (II-Gr.) another year later and (4) of 3-year-old cod (III-Gr.) of yet another year later. The material for the determination of the amounts of 0—III-Gr. fish originates from the experimental fishings of the Biological Station with the eel-seine.

I beg to render my best thanks to cand. mag.

[1]) Erik M. Poulsen: Biological Investigations upon the Cod in Danish Waters. Medd. fra Komm. f. Danmarks Fiskeri- og Havundersøgelser. Ser. Fiskeri, IX, 1. 1931.

Mrs. E. Bohus Jensen, who has assisted me in the working up of the figures, Capt. H. C. Christensen, who has grouped the material from the fishing experiments of the Biological Station, and Mag. sc. P. Heegaard, who has sorted out the material of fish eggs collected from the light-vessels.

I. The annual fluctuations in the amount of fry.

1. General remarks. Nature and extent of the material.

In most species of fish there may be—and generally are—very great annual fluctuations in the amount of fry, that is to say in the quantity of larvae appearing as the result of the annual spawning. At Norway such fluctuations were established in the case of herring and cod (Joh. Hjort, 1914)[1]). During the period 1923—39 the Danish waters have shown nearly 40 times as many cod larvae in the richest as in the poorest year. The cause of such huge changes in the amount of fish fry is the fact that the fishes, especially the species which—like the cod—have pelagic eggs, during every spawning lay an extremely great number of eggs (often as much as several hundred thousands or even several millions). The opposite state of things is found in mammals and birds where every litter or brood includes only one or quite a few young. The fishes thus seem to be much more prolific than the mammals, but the difference is only apparent: in fact the propagation of both groups of animals is equally intense because the stock of a given species of fish as well as of a given species of mammals maintains fairly the same size throughout thousands of years if no great changes are caused by the encroachment of exterior conditions or by man. The propagative advantage of the fishes against the mammals in their large numbers of eggs is counter-balanced by their nearly complete lack of care for the young: an elephant takes care of the young through many years, but the fish in most cases leaves its progeny completely to themselves, even before the egg is impregnated. The fact that the many eggs of the fish immediately after the spawning are fully exposed to the beneficial or injurious influence of exterior conditions induces the very great annual fluctuations that may appear in the amount of fish fry. If exterior conditions are good, a particularly great number of eggs are hatched, and particularly many larvae appear. If good conditions remain during the development of the larvae, the result will be an unusually large number of somewhat older brood, but if conditions grow bad, the abundance of larvae will result in no very great stock of brood of a little higher age. On the other hand particularly good conditions during the development of the larvae may to some extent remedy bad conditions at the time when the embryo develops in the egg. In other words various exterior factors at various points of time affect the development of the eggs spawned, and the amount of fry at last appearing is conditioned by an interaction of these different factors. In some years this interaction is particularly favourable to the brood, and so we get the rich brood years; in other years the infavourable result of the interaction causes the occurrence of poor brood years. In this way the large numbers of eggs together with the very marked influence of exterior conditions caused by the lack of care of the fry thus create the possibility of the extremely great annual fluctuations in the amount of fry. In order to understand how the stock of marketable fish is created it is therefore important partly to examine how the amount of fry of a given species of fish fluctuates from year to year, partly to attempt to elucidate the conditions that give rise to the fluctuations in the amount of fry.

The material published in 1931 with a view to throwing a light on the annual fluctuations in the amount of cod larvae covered a comparatively short period, the years 1923—29, but in spite of this we could see that some years were characterized by very rich occurrences of fry, other years showing a very sparse occurrence. It further turned out that the period of investigation, short as it was, showed a considerable correspondence between the fluctuations in the amount of larvae and the changes in the temperature of the bottom water in March, April and May, *i. e.* the months in which the cod larvae

[1]) Joh. Hjort: Fluctuations in the great Fisheries of Northern Europe. Rapp. et Proc. Verb. du Cons. Int. p. l'Expl. de la Mer. XX. 1914.

principally appear, in such a way that many larvae occurred in years when the temperature was comparatively high and few larvae in years with low temperature. It was emphasized that the cause of this connexion was undoubtedly found in the fact that the amount of plankton and, consequently, of nourishment was greatest in springs with high temperatures. Within the period examined a connexion further existed between the amount of larvae in April and May and the salinity of the bottom water in November—December of the previous year, a high salinity being followed by a large amount of larvae and vice versa. The cause of this co-variation was not obvious, but it was pointed out that it might be due to a high salinity in early winter causing an increased immigration or a decreased emigration of grown-up cod ready to spawn, that is to say to an increased extent of spawning in the following spring. Aage J. C. Jensen (1933)[1]) found a similar correspondence between the amount of plaice fry of the 0-Gr. in summer and the salinity of the bottom water in November—December of the previous year and offers the explanation that more plaice of the North Sea race remain in our inner waters in order to spawn if the salinity is high in the winter months.

As the period on which these results are based is rather short—including 7 years only—there is a reason now, that the material of another 10 years is available, to subject the whole question of the fluctuations in the quantity of larvae to a renewed investigation.

Throughout all 17 years the fishings for larvae were carried out with the same gears and in the same areas of water, in most cases even in the same localities. We may therefore expect the material of the different years to show the highest possible degree of comparability of such investigations. In the great majority of cases the fishings for the larvae were carried out with the ringtrawl, but in quite a few cases the young-fish-trawl was used. Both gears are made of the same material, stramin with 6—8 threads to the centimetre. The young-fish-trawl has a rectangular mouth and is spread out by means of bords while the ring-trawl has a circular mouth kept open by an iron ring of 2 m. in diameter. The opening of both gears is the same, 3.1 sq.m., so that they have the same fishing power. Every haul generally lasts 30 minutes, in a few cases somewhat more or less. The gear was towed through the water at a rate of $1^1/_2$ naut. mile per hour; assuming that all the water coming within the reach of the opening is filtered, a 30 minutes' haul thus filters a body of about 4 400 cb.m. of water. At greater depths—below 20 m.—hauls were nearly always made at two depths (in particularly deep water sometimes at 3 or 4 depths), in which cases the mean numbers of larvae caught in the 2 (or more) hauls were used for the calculation. In some years only one haul was made even in deeper water, but in these cases some of the wire was taken in during the haul, so that the trawl for half the time was fishing in deeper, for the other half in the upper layers of water. In these cases the number of larvae captured expresses the amount of larvae both in the upper and lower water layers, thus corresponding to the mean figures otherwise calculated on the basis of the different hauls at several depths of the same station. When the fishing time deviated from 30 minutes, the catch figure was calculated to this time.

In the years 1923—26 part of the hauls were made by night, but in the years after 1926 all the hauls were made by day. During the former period, however, the hauls made by night were but few as compared to the total number and will hardly cause any great disturbance in a comparison of the catch figures of these years to those of the later years, more particularly so because the cod larvae do not belong to the fishes that are notorious for being caught in far greater numbers by night than by day (A. C. Johansen, 1925)[1]).

Table 1 gives the numbers of cod larvae caught per 30 minutes in the ring-trawl or the young-fish-trawl in various Danish waters within the Skaw in April, May and June of the years 1923—39. The table further gives the mean figure for the two months of April and May; the mean catch of these two months was used for the investigations to be dealt with here. However, in the western Baltic and the Baltic proper the catch figures for June (if

[1]) Aage J. C. Jensen: Periodic Fluctuations in the Size of Various Stocks of Fish and their Causes. Medd. fra Komm. f. Danmarks Fiskeri- og Havunders. Ser. Fiskeri. Vol. IX. 1933.

[1]) A. C. Johansen: On the diurnal vertical Movements of Young of some Fishes in Danish Waters. Medd. fra Komm. for Havunders. Ser. Fiskeri. VIII, 2. 1925.

Table 1. Numbers of cod larvae caught per 30 minutes' haul with the ring-trawl (or the young-fish-trawl) in various waters during the years 1923—39. Small figures denote the number of stations.

Year		1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	Mean
April	Northern Kattegat	4 10	0 3	32 8	5 5	..	..	..	14 5	..	..	..	10 2	30 3	1 3	22 4	..	..	15
	Southern —	47 11	6 2	59 13	6 6	6 3	..	29 15	15 18	10 5	70 6	24 11	90 17	45 20	4 19	38 18	398 17	19 10	54
	The Sound	42 5	..	228 3	16 3	..	..	52 7	3 2	4 2	8 7	10 7	41 8	45 2	3 5	15 4	365 3	61 6	64
	The Belt Sea	102 5	4 5	62 6	15 2	64 15	..	16 16	11 44	12 27	23 18	6 9	33 9	62 33	13 31	44 25	211 29	41 14	45
	Western Baltic	7 12	..	22 5	0 1	84 3	..	6 4	4 5	2 4	3 4	..	..	183 4	18 3	15 2	211 2	119 3	52
	Baltic proper	9 7	..	7 9	..	..	..	..	1 6	..	1 13	1 11	..	18 3	4 7	1 7	5 5	..	52
	Mean	35	3	68	8	51	..	26	8	7	21	10	44	64	7	23	238	60	42
May	Northern Kattegat	85 6	..	..	6 7	14 3	..	14 5	3 6	2 2	..	..	..	..	..	..	..	6 2	19
	Southern —	105 7	..	..	8 4	7 2	..	76 19	9 19	3 1	20 3	53 6	14 1	2 1	..	11 12	13 4	13 5	26
	The Sound	295 2	..	..	..	..	..	..	..	8 7	..	..	..	33 3	..	0 1	21 6	7 3	61
	The Belt Sea	181 8	0 1	..	5 10	15 2	21 7	42 49	6 18	0 1	..	36 21	20 11	38 12	24 10	15 8	59 20	11 22	32
	Western Baltic	..	..	13 2	7 7	..	..	17 14	..	11 1	..	24 5	39 2	..	..	..	41 6	16 8	20
	Baltic proper	..	..	18 3	11 9	..	..	..	..	0 2	..	..	..	3 7	..	..	7 11	1 8	67
	Mean	167	0	16	7	12	21	37	6	4	20	38	24	19	24	9	28	9	26
June	Northern Kattegat	..	..	..	..	..	..	..	0 5	2 2	..	..	..	..	..	..	..	..	1
	Southern —	..	..	..	..	..	22 3	..	0 5	3 1	..	0 2	..	..	..	..	..	..	6
	The Sound	29 2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	29
	The Belt Sea	451 4	..	..	..	4 1	18 15	9 17	1 28	..	0 1	..	0 4	..	..	..	0 1	..	60
	Western Baltic	654 10	..	..	..	..	12 2	..	1 5	..	..	..	..	..	..	..	..	..	222
	Baltic proper	18 13	..	..	..	..	..	..	0 2	..	..	..	..	..	..	..	..	..	9
	Mean	288	..	..	..	4	17	9	0	3	0	0	0	..	..	..	..	..	36
April + May	Northern Kattegat	45 16	0 3	32 8	6 12	14 3	..	14 5	9 11	2 2	..	..	10 2	30 3	1 5	22 4	..	6 2	15
	Southern —	76 18	6 2	59 13	7 10	7 5	..	53 34	12 37	7 6	45 14	39 17	53 18	24 21	4 19	25 30	206 21	16 15	40
	The Sound	168 7	..	228 3	16 3	..	..	52 7	3 2	6 9	8 7	10 7	41 8	39 5	3 5	8 5	193 9	34 9	58
	The Belt Sea	142 13	2 6	62 6	10 12	40 17	21 7	29 65	9 62	6 28	23 18	21 30	27 20	50 45	19 41	30 33	135 49	26 36	38
	Western Baltic	7 12	..	18 7	4 8	84 3	..	12 18	4 5	7 5	3 4	24 5	39 2	183 4	18 3	15 2	126 8	68 11	41
	Baltic proper	9 7	..	13 12	11 9	..	..	..	1 6	0 2	1 13	1 11	..	11 10	4 7	1 7	6 16	1 8	5
	Mean	75	3	69	9	36	21	32	6	5	16	19	34	56	8	17	133	25	30

available) are included in the calculation because in these waters the spawning occurs a little later than in the rest of our waters. The results of fishing experiments in the month of March were not included in the table because investigations of some extent in this month were made only in one year, 1927. In the following table are found the catches (numbers per 30 minutes) in March, April and May of 1927, numbers of hauls in ():

	March	April	May
The Kattegat	28 (2)	6 (3)	9 (6)
The Belt Sea	7 (32)	67 (26)	15 (4)
Western Baltic	2 (1)	84 (6)	

The figures seem to show that the full number of larval cod in the Belt Sea and the western Baltic have not yet been developed in March, whereas this is possibly the case in the Kattegat.

Of the Baltic proper only the westernmost part W. of Falsterbo—Hiddensø was included in the investigation.

2. The influence of temperature on the time at which the larvae appear.

The development of the cod larvae does not show the same time of beginning or the same rapidity in the different years. If we compare the catches of larvae per 30 minutes in the two years that show the most abundant occurrence of larvae, 1923 and 1938, we find a distinct difference:

	1923		1938	
	April	May	April	May
Northern Kattegat	4	85	..	..
Southern —	47	105	398	13
The Sound	42	295	365	21
The Belt Sea	102	181	211	59
Western Baltic	7	..[1])	211	41
Baltic proper	9	..[2])	5	7
Mean...	35	167	238	28

In 1923 the catches of May were 5 times as great as those of April, whereas in 1938 the catches of April were 8 times as great as those of May. This difference is undoubtedly a consequence of the development of the cod larvae occurring earlier and more rapidly in 1938 than in 1923. The temperatures of the sea-water also show a conspicuous difference in the late winter and spring of 1923 and 1938, for which two years the subjoined table gives the temperatures at 20 m. depth at the light-vessels of Schultz' Grund (S. G.), Lappegrunden (L. G.) and Halskov Rev (H. R.):

	1923				1938			
	S.G.	L.G.	H.R.	Mean	S.G.	L.G.	H.R.	Mean
Jan.	4.7	5.2	4.7	**4.9**	8.3	7.9	6.1	**7.4**
Feb.	2.8	3.1	2.0	**2.6**	4.1	3.8	3.5	**3.8**
Mar.	4.0	5.0	3.0	**4.0**	4.5	4.4	4.2	**4.4**
Apr.	4.0	5.9	4.7	**4.9**	4.5	5.8	4.5	**4.9**
May	6.6	7.1	5.6	**6.4**	6.8	6.5	6.5	**6.6**

It appears distinctly from these measurements of temperature that the temperature of the sea-water throughout the winter and the early spring of 1938 was considerably higher than in 1923. Most probably the warmer water of the late winter of 1938 has brought about a comparatively early spawning of the cod or a comparatively rapid development of the larvae or both; therefore it is but natural that the maximum of their abundance should occur earlier in 1938 than in 1923.

The fact that the larvae in some years show the greatest frequency in April, in others in May involve that we cannot be content to consider the catch figures of one month only if we want to get an image of the change from year to year in the frequency of the larvae. Judging by April alone 1923 would barely and by May alone 1938 would only be average years. The calculations used in the present paper therefore do not base on one month but on the mean catch of April—May: in this way we are able, to a certain degree, to eliminate the uncertainty caused by the quicker or slower development of the larvae in the individual years. Also in March and June considerable quantities of larval cod occur in Danish waters, in March particularly in the Kattegat, in June mainly in the Baltic; but fishings for larvae in these two months were carried out in quite a few years only, so that it was not possible to include them in the calculations.

3. The frequency of the larvae in our different waters.

There is a rather considerable difference in the size of the catch figures for cod larvae in our different waters. The following table gives the mean numbers

[1]) In June the mean catch was 654 per 30 minutes.

[2]) In June the mean catch was 18 per 30 minutes.

of larvae caught per 30 minutes in April—May in the different waters; for this calculation only such years were used (9 in all) in which all waters were fished.

Northern Kattegat	17
Southern —	26
The Sound	50
The Belt Sea	39
Western Baltic	36
Baltic proper, W. part	6

In other words the largest numbers of cod larvae are found in the Sound; they are less numerous in the Belt Sea, the western Baltic and the southern Kattegat, and the smallest numbers are found in the northern Kattegat and the western part of the Baltic proper. There is reason to believe that the northern Kattegat would have shown a somewhat larger amount of larvae if the investigations had been carried out at an earlier point of the spawning time (in February—March). In the central part of the Baltic proper (the water round Bornholm), which, however, is not dealt with here, there is—at any rate in some years—a rather dense stock of cod larvae, though later in the year, in June or even later. E. of Bornholm the cod may even spawn as late as August—September (R. Kändler, 1938)[1]).

4. The annual fluctations in the amount of larvae.

There is a very great variation from year to year in the amount of cod larvae. If we look at the figures of the bottom line of Table 1, where the mean catches per 30 minutes are given for all waters collectively, we see that the mean catch ranges between 3 and 133 per 30 minutes. If we take the waters separately, the difference is even greater: in the Belt Sea only 2 larvae were taken per 30 minutes in April—May of the poorest year (1924) as against 142 in the best year (1923), or 71 times as many. For all waters in one the mean catch of 5 years is below 10, but that of 4 years above 50. The mean catch for all years together is 30.

To which degree, then, do these figures express the actual fluctuations of the amount of larvae in our waters? May we take it for granted that the investigations carried out have been comprehensive enough to give a reliable idea of the amount of larvae in our waters in the individual years? It will be necessary to enter into the details of this problem because the value of the investigations to be dealt with in the following depends on the possibility of answering this question in the affirmative. Behind every mean figure of the table is given the number of stations on which the calculation of it was based;

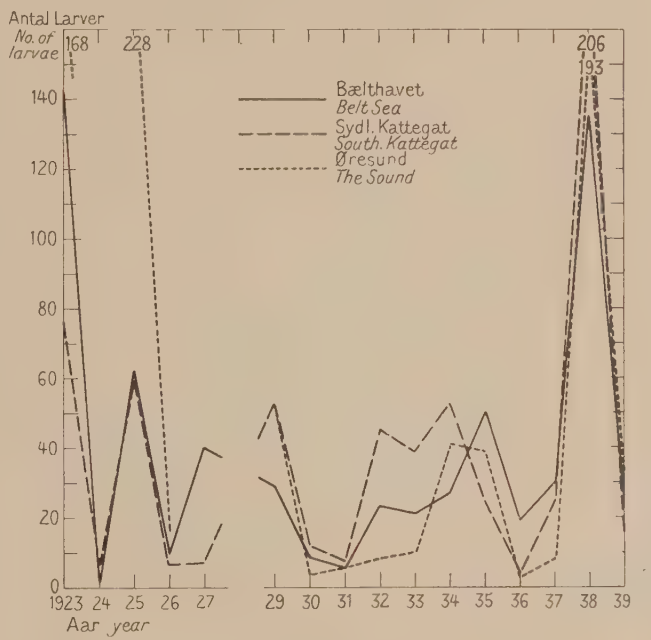

Figure 3. Numbers of cod larvae caught per 30 minutes' haul with the ring-trawl in April + May of the years 1923—39 in the Belt Sea, the southern Kattegat and the Sound.

of course the mean figure found is the more reliable, the more stations have been worked. The largest numbers of stations occur in the Belt Sea and the southern Kattegat, where between 20 and 50 stations have mostly been worked per annum. In the other waters the numbers of stations are generally considerably lower. In the following, therefore, the stress will mainly be laid on the results from the Belt Sea and the southern Kattegat.

The waters dealt with here being of rather small extent, reaching only from the Skaw to Rügen, there is reason to suppose that the hydrographical factors and other circumstances (for instance the quantity of spawning cod) inducing the poorer or richer occurrence of the cod fry will vary in fairly the same way from year to year within the waters,

[1]) Rudolf Kändler: Untersuchungen über das Laichen des Ostseedorsches im Herbst. Kieler Meeresforschungen, II. 1938.

so that rich and poor occurrences of larvae will occur in the same year in the different waters. In examining to which extent the annual fluctuations found in the amount of larvae agree in the different areas of water we shall therefore be able to decide whether, on the basis of the number of stations worked, it is possible with some degree of safeness to point out the springs that are characterized by particularly rich and by particularly poor occurrences of larvae.

From a view at Table 1, which states the average catch figures for larvae in different years and waters, and at Figure 3 with its representation of the annual fluctuations in the amount of larvae in the southern Kattegat and the Belt Sea it will appear that the quantity of larvae in the different waters varies in comparatively the same way from year to year. In 1923, 25 and 38, for instance, the amount of larvae was very great in all waters while the years 1924, 26, 31, 36 and 39 for all waters show a rather or very sparse occurrence of larval cod.

As a matter of fact a mathematical calculation of the connexion between the annual fluctuations in the amounts of larvae in the different waters clearly shows a considerable degree of correspondence between them, the following correlations having been found from one water to the other[1]) (the found correlations together with the boundaries of the waters are shown on the map, Figure 4):

Water	Period 1923—39	Coefficient of correlation (r)	Mean error (σ_r)
North. Kattegat—South. Kattegat	13 years	$+0.756$	± 0.119
South. Kattegat—the Sound	14 —	$+0.658$	± 0.135
South. Kattegat—Belt Sea	18 —	$+0.785$	± 0.096
Belt Sea—Western Baltic	15 —	$+0.843$	± 0.072
The Sound—Baltic proper	12 —	$+0.643$	± 0.170
Western Baltic—Baltic proper	12 —	$+0.639$	± 0.170

Correlation means co-variability, and the degree to which there is a co-variability of the two factors compared is indicated by the coefficient of correlation, which is calculated from the way and the degree in which the individual series of figures compared (in this case the numbers of larvae caught per 30 minutes in the individual years in one area of water and in the other) deviate from their mean for all the years examined. The coefficient of correlation may vary between $\div 1$ and $+1$. The more the coefficient deviates from 0 and approaches $+1$ or $\div 1$, the greater is the co-variability of the two factors; if the coefficient is positive ($+$), the two factors deviate in the same direction from their mean, if it is negative ($\div$), they deviate in the opposite directions. The mean error, which is given with the sign of $\pm$, is expressive of how safe the found correlation is; it is generally agreed that the correlation must be nearly 3 times as great as its mean error to be considered safely established[1]).

As will be seen there is in all cases a distinct positive correlation, which is considerably above 3 times its mean error. This means that a close correspondence has been demonstrated between the annual fluctuations in the amount of larvae in the different waters in such a way, that in years when many larvae are found in one water there are also many larvae in other waters. In other words the investigation shows that within the comparatively limited area of waters between the Skaw and Rügen there are uniform fluctuations from year to year in the amount of larvae. This is of course what might be expected, but the fact that it has been possible to demonstrate this correspondence so distinctly on the basis of the material in hand shows that this material is comprehensive enough to afford a considerable degree of safety in the demonstration of the annual fluctuations of the quantity of larvae in our waters.

If in Table 1 we look at the row of figures stating the mean numbers of larvae caught per 30 minutes in April—May in all waters collectively, it is seen that within the 17 years covered by the investigations no changes in the amount of larvae in one direction or the other can be established throughout the years. Rich and poor occurrences of larvae alternate and are found both at the beginning and at the end of the period. If the 17 years are divided

[1]) For the western Baltic and the Baltic proper was used the mean number of larvae from April—June, for the rest of the waters the mean number from April—May.

[1]) The coefficient of correlation r is calculated from the formula $r = \frac{\Sigma ab}{\sqrt{\Sigma a^2 \cdot \Sigma b^2}}$ and its mean error σ_r from the formula $\sigma_r = \frac{1 - r^2}{\sqrt{N}}$.

Figure 4. Map showing the boundaries of waters used in the examination of the material of larvae together with the correlations between the annual fluctuations in the amount of larvae from one water to the other. On the map we further find the positions of the 4 light-vessels of Østre Flak, Anholt Knob, Schultz' Grund and Halskov Rev.

into 3-years' periods, we get these mean figures for each period:

Period	1923—25	1926—28	1929—31
Number of larvae.....	49	20	14
Period	1932—34	1935—37	1938—39
Number of larvae.....	23	27	68

Accordingly, there have been comparatively rich occurrences of larvae at the beginning and the end of the 17-years' period while the intermediate years have been rather poor. But within these years there has been no universal decrease or increase of the amount of larvae, which again may be taken to

mean that our stock within the said time has neither diminished nor increased to a perceptible degree.

A look at Table 1 and Figure 3 will show that within the series of years examined we have had two decidedly rich brood years: 1923 at the beginning and 1938 near the end of the time. For April—May the mean catches of all waters are 75 larvae per 30 minutes in 1923 and 133 per 30 minutes in 1938. In these two years there were heavy catches of larvae in all waters except the western part of the Baltic proper though here, too, the catches were above mean. In 1923 most larvae were caught in the Sound and the Belt Sea, in 1938 the richest occurrences were in the Kattegat and the Sound. The third best year of larvae was 1925, when especially the Sound exhibited a large quantity, 228 per 30 minutes or the record mean capture for one water. 1935, too, was a good brood year. In 1927, 1929, 1934 and 1939 the numbers of larvae (25—34 per 30 minutes) ranged about the normal of the whole period (30 per 30 minutes). Rather poor brood years were 1928, 1932, 1933 and 1937 with 16—21 larvae per 30 minutes, and quite poor brood years we had in 1924, 1926, 1930, 1931 and 1936, the catches of these years ranging between 3 and 9 specimens per 30 minutes.

It appears from this that the amount of cod larvae is subject to very great fluctuations from year to year in Danish waters, and generally speaking the fluctuations are uniform throughout the waters. The fluctuations are so great, that nearly 50 times as much fry may be produced in one year as in the other.

II. On the causes of the fluctuations in the amount of larvae.

1. Fluctuations in the amount of cod eggs and the extent of the spawning.

In the previous section a statement was given of the very great fluctuations in the amount of cod larvae in Danish waters; in some years the mean capture per 30 minutes is as low as 2—3 specimens per 30 minutes, in other years it is more than 100. Of course the question now suggests itself: what is the cause of these fluctuations?

The length of the larvae fished ranges between about 5 and about 20 mm., by far the greatest number being between 8 and 15 mm. long, *i. e.* larvae of about 1—4 weeks of age. Consequently, the causes must be found among the conditions influencing (1) the quantity of eggs spawned, (2) the impregnation of the eggs, (3) the development of the embryo in the egg or (4) the thriving of the larvae within their first month of life.

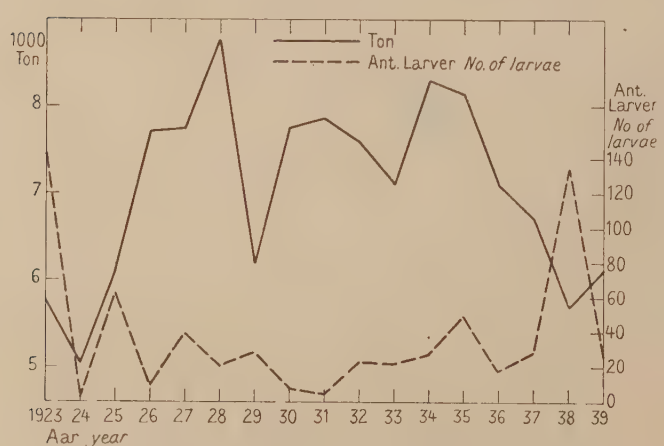

Figure 5. Comparison between the number of cod larvae caught in the Belt Sea per 30 minutes in April—May and the amount of cod fishes in the same water for the years 1923—39.

As to the first point, the quantity of eggs spawned, it is evident that it depends on the number of spawning cod and on their weight because a big cod lays many times more eggs than a small one, which means that the number of eggs depends on the weight amount of the spawning cod. We have no exact expression for the weight amount of spawning cod in our waters, but we get an idea of the fluctuations from one year to another if we look at the fluctuations of the yield of the cod fishery because the greater part of the catches consists of mature cod. An approximate expression of the degree to which the amount of larvae depends on the extent of the spawning we may thus get by comparing the yield of the fishery to the amount of larvae. If we find a certain connexion between the fluctuations of these two factors, there will be reason to believe that the amount of larvae to a considerable degree depends on the extent of the spawning.

In Figure 5 we find a comparison between cod fished in the Belt Sea in the years 1923—39 and the number of larvae caught per 30 minutes in April

and May in the same water. It appears at once from the run of the graphs that there is no very pronounced connexion between catch yield and amount of larvae: there is no rich occurrence of larvae corresponding to the heavy catch yields in 1928 and 1934, neither do the rich occurrences of larvae in 1923 and 1938 coincide with heavy catch yields. The spawning takes place in winter, from December to March, while the catch yields refer to the whole twelvemonth and thus do not represent the quantity of cod in the spawning time alone. Therefore a comparison like that carried out here is of course rather unsafe; we might nearly just as well compare the amount of larvae in one year to the catch yield of the previous year. But such a comparison does not either support the idea of a connexion between the amount of cod and the number of larvae. A calculation of the correlation between the amount of larvae and the catch yield of the previous year for the Belt Sea gives a coefficient of $\div 0.338$ with a mean error of ± 0.215. A somewhat safer method of examining the dependence of the amount of larvae on the number of spawning cod is to compare the mean figure for the amount of larvae in a short series of years to the catch yields of the same period, by which means we shall learn whether particularly many larvae appear in periods with a large cod population. This has been done in the subjoined table, which shows the catches of cod in 3-years' periods as compared to the number of larvae caught per 30 minutes in April—May in the Belt Sea during the same periods:

Series of years	Catch of cod in tons, annual mean	No. of larvae caught per 30 minutes
1923—25	5.656	69
1926—28	7.973	24
1929—31	7.173	15
1932—34	7.685	24
1935—37	7.375	33
1938—39	5.979	77

The correlation between the amount of larvae and the catch yield is $\div 0.899$ and the mean error ± 0.078. Here, then, there is an extremely pronounced negative correlation, *i. e.* the periods with many cod are characterized by comparatively few larvae and *vice versa*, so that there is nothing to indicate that the amount of larvae should be conditioned by the number of grown-up cod and, accordingly, by the intensity of the spawning.

As already mentioned the catch yield of the year is no safe equivalent to the number of cod found during the very spawning time. It is a matter of general knowledge that a considerable number of big cod immigrate into our inner waters (the Belt Sea) in the months of autumn—in other words immediately before the spawning; such migrations were also established directly by markings of cod (A. C. Strubberg, 1922)[1]). In this way the stock of our inner waters just before the spawning time is increased by a certain contingent of big, mature cod from without, and it might therefore be supposed that the size of this contingent could influence the amount of eggs spawned and, consequently, the amount of larvae. The size of this contingent will only in part emerge from a study of the statistics on the annual catch yield because the statistics cover the whole year and not only the time (the winter) affected by the immigration. These immigrating cod arrive from without, that is to say from salter water; it must therefore be supposed that the immigration will be particularly great in years with a rapid inflow of salt water during the time of immigration (autumn and winter) and, accordingly, that we shall get a more extensive spawning and—if the intensity of the spawning influences the amount of larvae—a larger amount of larvae in springs following on such an increased immigration. In fact my treatise of 1931 established such a connexion for a shorter series of years between the height of the salinity in November—December and the amount of larvae in the following spring. We shall now examine whether the more comprehensive material now in hand shows a similar connexion. In the subjoined table we find the correlation between the amount of larvae in the Belt Sea in April—May (mean catch per 30 minutes) and the salinity of surface and bottom water at the Halskov Rev Lightvessel during the time before the spawning in the years 1923—39.

Amount of larvae correlated with salinity 0 m. at Halskov Rev.

October	$\div 0.525$	± 0.176
November	$+ 0.252$	± 0.227
December	$+ 0.194$	± 0.234
January	$+ 0.389$	± 0.212
February	$+ 0.106$	± 0.267

[1]) A. C. Strubberg: Marking Experiments with Cod (*Gadus callarias* L.) in Danish Waters. Medd. fra Komm. f. Havundersøgelser. Ser. Fiskeri. VII, 1. 1922.

Between the salinity of the surface water and the amount of larvae there is thus a fairly safe negative correlation for October, but a positive correlation has not been found, and so there is nothing to indicate a connexion between the salinity of the surface water and the amount of larvae. As, however, an inflow of salt water makes itself felt first and foremost in the lower water layers, we shall sooner expect to find a positive correlation with the salinity of these water layers:

October	$+0.163$	± 0.236
November	$+0.581$	± 0.161
December	$+0.095$	± 0.241
January	$+0.359$	± 0.217
February	$+0.265$	± 0.251

Here there is a distinct positive correlation for November, but not for any other month. For November—December in one the correlation is $+ 0.521 \pm 0.177$: being very nearly 3 times as great as its mean error it must be considered comparatively safe. If a similar calculation is made for the southern Kattegat between the amount of larvae caught per 30 minutes in April—May and the salinity of the bottom water at the Schultz' Grund Light-vessel in November—December of the previous year, the correlation is found to be $+ 0.541 \pm 0.177$; here, too, the correlation is about 3 times as great as its mean error. For all waters collectively, the Kattegat + the Sound + the Belt Sea + the western Baltic, the correlation between the number of larvae per 30 minutes[1]) and the salinity of the bottom water at the Schultz' Grund and the Anholt Knob in November—December of the previous year for the period 1902—39 is $+ 0.361 \pm 0.185$: here the correlation is about 2 times as great as its mean error. These positive correlations thus seem to indicate the existence of a certain, though not very pronounced connexion between the amount of spawning cod and the amount of larvae. This connexion is most likely to be explained in the following way: in years with high salinities in our inner waters in autumn and early winter there is either a considerable immigration of big—and therefore mainly mature—cod, or these cod will in such years remain for a longer time than normally in our inner waters with a subsequent larger extent of their spawning here. These circum-

[1]) For the western Baltic April—June, for the other waters April—May.

Table 2. Mean numbers of cod eggs taken per haul from bottom to surface with the Hensen net from the light-vessels of Halskov Rev, Schultz' Grund and Anholt Knob in the months of December—May, 1928—40.

Halskov Rev:

	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total
1928/29	?	?	?	?	6	0.5	..
29/30	1	6	45	13	3	0.3	68
30/31	?	6	31	19	16	3	75
31/32	1	19	5	9	7	0.5	42
32/33	?	19	14	51	6	0.8	91
33/34	1	15	33	32	6	0.3	87
34/35	?	23	93	27	16	3	162
35/36	2	30	27	27	14	0	100
36/37	1	9	57	103	40	0	210
37/38	5	29	37	18	3	0	92
38/39	?	4	33	4	9	0	50
39/40	3	1	?	?	34	4	42
Mean	2.0	14.6	37.5	27.6	13.5	1.0	96.2
M. percent.	2.1	15.2	38.9	28.7	14.0	1.1	100

Schultz' Grund:

	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total
1928/29	?	?	?	?	0	2	..
29/30	5	39	15	35	5	0	99
30/31	3	18	28	21	6	4[1])	81
31/32	4	14	24	18	11	0	71
32/33	5	23	21	26	4	0.5	80
33/34	3	44	82	30	5	0	164
34/35	17	31	25	12	14	0.3	99
35/36	14	32	28	31	6	0.8	112
36/37	4	5	66	52	2	0	129
37/38	10	38	61	4	4	0	117
38/39	7	33	52	14	6	0	112
39/40	4	8	?	?	2	1	15
Mean	6.9	25.9	40.2	24.3	5.4	0.7	103.9
M. percent.	6.6	24.9	38.7	23.4	5.2	0.7	100

Anholt Knob:

	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total
1928/29	?	?	?	?	1	0	..
29/30	1	7	16	8	1	0	33
30/31	0	4	6	5	0.5	0	16
31/32	?	9	10	23	4	0.9	47
32/33	0	4	7	12	2	0	25
33/34	1	15	10	19	2	1	48
34/35	?	6	5	10	9	0.5	31
35/36	2	15	13	7	2	0.5	40
36/37	1	3	15	13	5	0.3	37
37/38	2	7	8	8	0.4	0	25
38/39	?	14	4	7	0.3	0.5	26
39/40	24	0	?	?	4	0	28
Mean	3.7	7.6	10.4	11.2	2.7	0.3	35.9
M. percent.	10.3	21.2	29.0	31.2	7.5	0.8	100

[1]) In June 0.5 egg was taken per haul in 1931; in no other year cod eggs were taken in June.

Table 2 (continued).

Mean of all light-vessels:

	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total
1928/29.....	?	?	?	?	2	0.8	..
29/30.....	2	18	25	19	3	0.1	..
30/31.....	1.5	9	22	15	8	2.3	..
31/32.....	2.5	14	13	17	7	0.5	..
32/33.....	2.5	15	14	30	4	0.4	..
33/34.....	2	25	42	27	4	0.4	..
34/35.....	17	20	41	16	13	1.3	..
35/36.....	6	26	23	22	7	0.4	..
36/37.....	2	6	46	56	16	0.1	..
37/38.....	6	25	35	10	2	0	..
38/39.....	7	17	30	8	5	0.2	..
39/40.....	10	3	?	?	13	1.7	..
Mean.....	5.3	16.2	29.1	22.0	8.4	0.7	81.7
M. per cent..	6.5	19.8	35.6	26.9	10.3	0.9	100

stances thus seem to indicate that the number of larvae appearing may to some extent be influenced by the amount of spawning cod. On the other hand it appears from the fact that no positive correlation can be established between the amounts of cod and larvae that the latter cannot chiefly be determined by the amount of spawning cod and that the great annual fluctuations in the amount of larvae are mainly caused by other factors.

That the number of eggs spawned (and, accordingly, to a certain degree the number of spawning cod) is not generally of essential importance to the amount of larvae further appears from the fact that it has not been possible to establish a connexion between the amounts of eggs and larvae on the basis of the material in hand. In the years 1929—40 weekly hauls with the Hensen net from bottom to surface have been made from the light-vessels of Anholt Knob, Schultz' Grund and Halskov Rev; in the months of January—April two hauls were mostly made per week, in the rest of the months only one. In Table 2 we find the average numbers of eggs taken per haul in the months of December—May (in November and June individual cod eggs were taken on very rare occasions) together with the mean figure of each month for all years collectively. It is further stated—also for all years in one—how large a percentage of the eggs was taken in each month. The table finally gives the corresponding figures for all light-vessels together. In Figure 6 we find a graphical representation of the numbers of eggs taken per 1 haul in the months of December—May. The figure shows that the eggs are much fewer at Anholt Knob than at Schultz' Grund and Halskov Rev where the numbers are nearly equally great. As far as the larvae are concerned (cp. Table 1), they are much fewer in the northern than in the southern Kattegat and the Belt Sea; therefore it is natural that the quantity of eggs should be smaller at

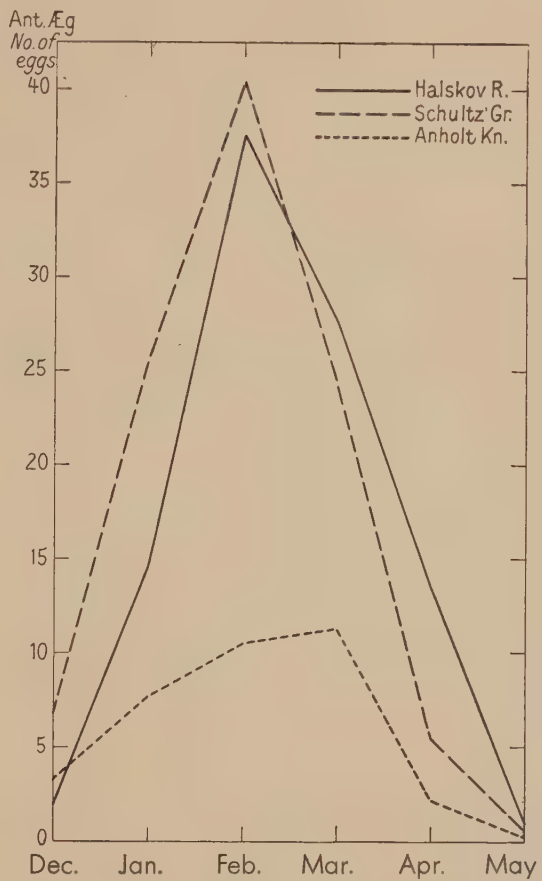

Figure 6. Numbers of cod eggs caught in the Hensen net per 1 haul from bottom to surface in each of the months of December to May from the light-vessels of Halskov Rev, Schultz' Grund and Anholt Knob in the years 1929—40.

Anholt Knob, which is situated on the border of the northern Kattegat, than at Schultz' Grund in the southern Kattegat and Halskov Rev in the Belt Sea. At all three light-vessels the amount of eggs is but small in December, but it rises rapidly in January and February. After this there is a slight fall or an unaltered amount in March; in April there is a rapid fall in the amount of eggs, and in May there are only quite a few cod eggs left. According to this January, February and March must be considered the prin-

cipal spawning time of the cod in the southern Kattegat and the Belt Sea: at all three light-vessels together 82 per cent. of the cod eggs were taken during these three months.

There is, of course, some change of the spawning time from year to year coincidently with the annual changes in the temperature of the sea-water. As will appear from Table 2 the spawning in January was of small extent in 1931, 1937 and 1940; the late beginning of the spawning in these years coincides with particularly low temperatures in January: at Halskov Rev in 1931 0.2°, in 1937 0.7° below the normal, and in 1940 the light-vessel had been withdrawn on account of ice in January (in December 1939 the temperature was 1.1° below the normal). In 1934, 1935, 1936 and 1938 the spawning was particularly extensive in January, and in these very years the temperature of this month was particularly high, being 1.5, 2.7, 2.3 and 2.2° above the normal, respectively. Thus it is evident that the spawning begins earlier in years with high than in years with low winter temperatures.

Whether the amount of larvae to any considerable degree depends on the amount of eggs will appear from an examination of the connexion between the numbers of eggs taken in the Hensen net in February-March and the numbers of larvae caught per 30 minutes in April—May. A calculation of the correlation between these two factors gives the following result:

Number of eggs at Halskov Rev—Number of larvae, Belt Sea	$+0.060$	± 0.315
Number of eggs at Schultz' Grund—Number of larvae, southern Kattegat	$+0.058$	± 0.315
Number of eggs at Anholt Knob—Number of larvae, north. + south. Kattegat	$\div 0.039$	± 0.316

Accordingly, no connexion can be established between the amounts of eggs and larvae, and there is hardly any reason to believe that the amount of eggs should influence the amount of larvae appearing to any considerable degree. In beforehand this might seem to be absurd. Nevertheless, it appears to be correct, and the reason is that the eggs spawned by the cod are so numerous—nearly $^1/_2$ mill. per 1 female —that there will always be enough to secure the hatching of the number of larvae for which the sea contains sufficient food, at any rate as long as the stock of cod does not fall below a certain minimum. As for other species of fish spawning a comparatively small number of eggs, for instance salmon and herring, the number of eggs will undoubtedly influence the amount of fry (in the case of the herring this was demonstrated by Aage J. C. Jensen)[1]).

As for species with many eggs the amount of eggs may undoubtedly come to affect the amount of larvae if the number of mother fish is very small; this is perhaps true of the Belt Sea plaice during recent years.

The observations made above thus show (1) that the amount of spawning cod hardly, and at any rate only very occasionally, affects the number of larvae appearing and (2) that the amount of eggs spawned does not either perceptibly influence the amount of larvae. It therefore seems to be evident that the amount of cod larvae is determined at a later time of the development than the spawning, in other words by the conditions prevailing at the time when the larvae are hatched and the time immediately after.

2. Salinity and temperature.

In the following it will therefore be examined whether a connexion exists between conditions in the sea on one hand, in the first line salinity and temperature in late winter and spring, and the amount of larvae on the other. To this purpose the following correlations with mean errors have been calculated:

Between the amount of larvae in the Belt Sea in April—May and the salinity of the surface water at the Halskov Rev light-vessel in the period January—May for the years 1923—39:

January	$+0.389$	± 0.212
February	$+0.106$	± 0.267
March	$\div 0.048$	± 0.256
April	$+0.254$	± 0.228
May	$+0.034$	± 0.244

It is seen that none of the correlations are 2, let alone 3 times the size of its mean error, and so there is no indication of the amount of larvae depending very much on the salinity of the surface water. Neither can a connexion be found between the

[1]) Aage J. C. Jensen: On the Influence of the Quantity of Spawning Herrings upon the Stock of the following Years. Journal du Conseil, Vol. II, 1927.

amount of larvae and the salinity of the bottom water, as will appear from the following correlations between the amount of larvae in the Belt sea in April and May and the salinity of the bottom water (20 m.) at the Halskov Rev Light-vessel (the years 1923—39).

January	+ 0.359	± 0.217
February	÷ 0.265	± 0.251
March	÷ 0.164	± 0.250
April	÷ 0.289	± 0.224
May	÷ 0.310	± 0.220

No connexion can thus be traced between the salinity of the sea-water in winter and spring and the amount of cod larvae.

Concerning a connexion between the temperature of the sea-water and the amount of larvae the following correlations have been calculated:

Between the amount of larvae in the Belt Sea in April—May and the surface temperature of the sea-water at Halskov Rev (the years 1923—39):

January	+ 0.370	± 0.209
February	+ 0.315	± 0.219
March	+ 0.433	± 0.197
April	+ 0.274	± 0.225
May	+ 0.004	± 0.243

In other words positive correlations have been found for all months, the greatest being those for January—March, but they are not so great as compared to their mean errors, that the changes in the temperature of the surface water can be supposed to affect the fluctuations in the amount of larvae very much.

Concerning the temperature of the bottom water and the amount of larvae the following correlations have been found between the amount of larvae in the Belt Sea in April—May and the temperature of the bottom water at the Halskov Rev Light-vessel (the years 1923—39):

January	+ 0.352	± 0.214
February	÷ 0.080	± 0.242
March	+ 0.162	± 0.238
April	+ 0.534	± 0.174
May	+ 0.619	± 0.152

There is no safe correlation for the months of January, February and March, but for April and May there is a distinct positive correlation; this correlation is more than 3 times as great as its mean error and must therefore be considered safely established. The examination consequently shows that in springs with a comparatively high temperature of the bottom water we have particularly large

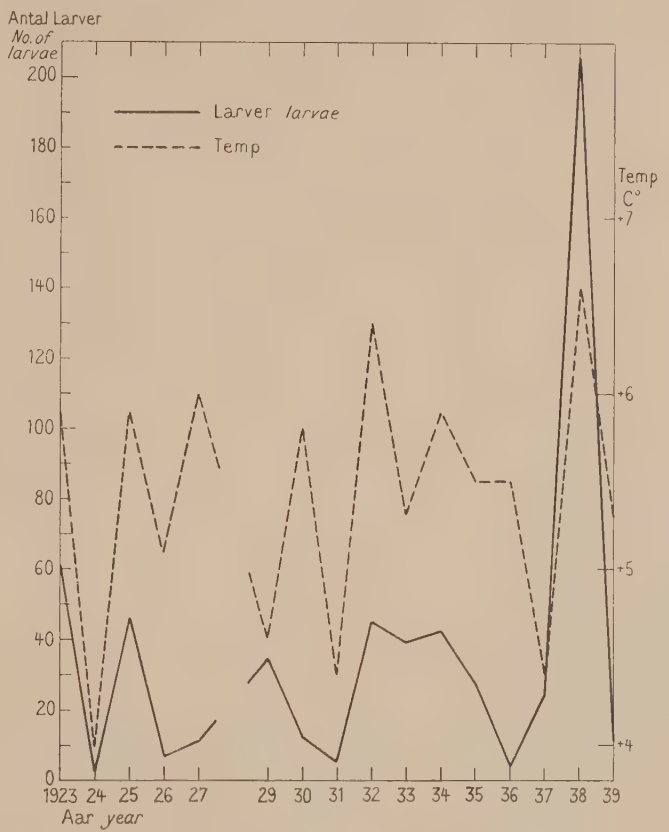

Figure 7. Annual fluctuations (1923—39) in the number of cod larvae caught in the ring-trawl per 30 minutes in the Kattegat in April + May compared to the temperature of the bottom water in April + May at the light-vessels of Anholt Knob (20 m.), Schultz' Grund (20 m.) and Østre Flak (10 m.) collectively.

amounts of larvae, but in years with a low bottom temperature the stock of cod larvae is rather sparse.

In the following we will examine whether such a co-variability is also found in other Danish waters from which we have fairly close investigations on the amount of larvae. As the distinct co-variability was found for the months of April and May, we have in the following calculations of the coefficient of correlation used the mean temperature for April + May and the mean catch per 30 minutes for the same months. In the western Baltic, where the cod larvae

develop somewhat later, the mean catch for April, May and June was used.

For the unbroken series of years with larval investigations (1923—39) the following correlations were found:

1. Larvae per 30 minutes, Belt Sea April + May—temperature Halskov Rev L.-v. 20 m. April + May: + 0.595 ± 0.158.

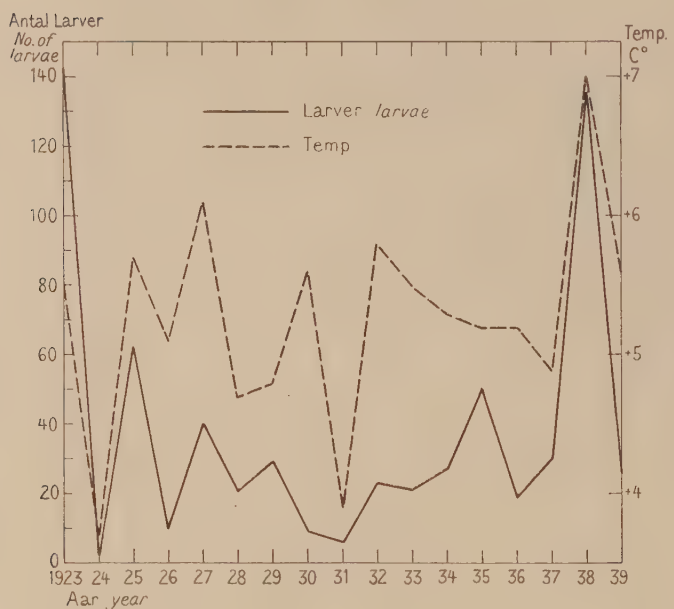

Figure 8. Annual fluctuations (1923—39) in the number of cod larvae caught in the ring-trawl per 30 minutes in the Belt Sea in April + May compared to the temperature of the bottom water at the Halskov Rev Light-vessel (20 m.).

2. Larvae per 30 minutes, southern Kattegat April + May—temperature Schultz' Grund L.-v. 20 m., Anholt Knob L.-v. 20 m. and Østre Flak L.-v. 10 m. April + May: + 0.521 ± 0.182.
3. Larvae per 30 minutes, southern + northern Kattegat April + May—temperature Schultz' Grund L.-v. 20 m., Anholt Knob L.-v. 20 m. and Østre Flak L.-v. 10 m. April + May: 0.579 ± 0.166.
4. Larvae per 30 minutes, Kattegat + Sound + Belt Sea + western Baltic April + May (+ June)—temperature Anholt Knob and Schultz' Grund 20 m. April + May: + 0.535 ± 0.173.

These calculations cover a period of 17 years. If we go further back in time and include a series of investigations from the years 1902—13, we get for this whole time of 28 years the following correlation between the amount of larvae per 30 minutes in the Kattegat, the Sound, the Belt Sea and the western Baltic and the temperature at 20 m. depth at the Anholt Knob and Schultz' Grund Light-vessels in April + May: + 0.503 ± 0.141.

All these correlations between the temperature of the bottom water and the amount of larvae are thus distinctly positive and somewhat greater than 3 times their mean error. In other words the investigations have clearly and safely shown that in our waters within the Skaw there is a distinct connexion between the fluctuations in the amount of larvae and the fluctuations in the temperature of the bottom water in April—May, in such a way that a rich stock of larvae is found in springs with a high temperature of the bottom water and a poor stock in springs with a low bottom temperature.

In Figures 7 and 8 the co-variability of the amount of larvae and the temperature of the bottom water is shown graphically for the Kattegat and the Belt Sea. It is seen that the graphs mostly show the same trend, the peaks and valleys of the two graphs generally occurring in the same years. The sudden big oscillations of the graph of temperature, for instance in 1923, 1924, 1931 and 1938 are always accompanied by corresponding oscillations in the graphs illustrating the amount of larvae.

The fact that the two items, temperature and amount of larvae, through a given series of years show the same variations from the normal, so that there is a distinct positive correlation between them, makes it probable that the amount of larvae depends on the temperature, but there is no proof of such a dependence. The result of the calculation of probabilities must therefore be combined with an examination of the question: what biological conditions can give rise to the dependence of the larvae on the temperature? The problem then is why comparatively high temperatures of the bottom water are favourable and comparatively low temperatures unfavourable to the development of the larval cod.

Here there may be either a direct or an indirect effect: a direct effect in particularly low temperatures being harmful or even fatal to the cod larvae, an indirect effect in the low temperatures impeding the development of the small animals and plants (plankton) constituting the basis of the nutrition of the larval cod. Of course the possibility also exists that there is both a direct and an indirect effect. If it were the direct influence of the temperature that

caused the annual fluctuations in the amount of larvae, we might expect to find the effects of this influence also on the development of the eggs (embryos). However, a comparison of the amount of eggs—that is to say the amount of living eggs capable of development—taken from the Halskov Rev, Schultz' Grund and Anholt Knob Light-vessels with the temperature of the lower water layers in the same localities shows no connexion between these two factors, for which the following correlations have been found:

Halskov Rev, amount of eggs per 1 haul with the Hensen net Febr.-March—temperature 20 m. Febr.-March: $+ 0.180 \pm 0.360$.

Schultz' Grund, amount of eggs per 1 haul with the Hensen net Febr.-March—temperature 20 m. Febr.-March: $\div 0.171 \pm 0.307$.

Anholt Knob, amount of eggs per 1 haul with the Hensen net Febr.-March—temperature 20 m. Febr.-March: $\div 0.329 \pm 0.282$.

There is nothing here to indicate a distinct connexion between amount of eggs and temperature, and so there is hardly reason to believe that the low temperatures as such have an impeding effect on the development of the larval cod. It would therefore seem probable that the effect of the temperature on the number of cod larvae is first and foremost of an indirect nature in that it affects other conditions, which in their turn influence the thriving of the cod larvae, in the first line the quantity of food (plankton).

3. The quantity of plankton.

When the larvae are hatched they have a yolk-sac, which contains food enough for some few days; but after this time they only get such food as they can find themselves. At this point of time the larvae are still delicate and weak, and their power of finding the necessary food themselves is but small. We may therefore take it for granted that it is of very great importance to the larvae that ample food is present at this very stage of their development, so that they can easily find the quantity of food necessary for their growth. Already in 1912 Johan Hjort (l. c.) pointed out that the critical stage during the development of the fishes are the very first larval stages when they are beginning to find their own food.

During the hatching of the cod larvae there is a rise of the quantities of plankton in our waters, as will be seen from Figure 9, which gives the amounts of plankton (in cm.^{3}) determined by hauls with the Hensen net (67 cm. in diameter) from bottom to surface at the Anholt Knob, Schultz' Grund and Halskov Rev Light-vessels. The graphs were plotted on the basis of the average quantity of plankton in

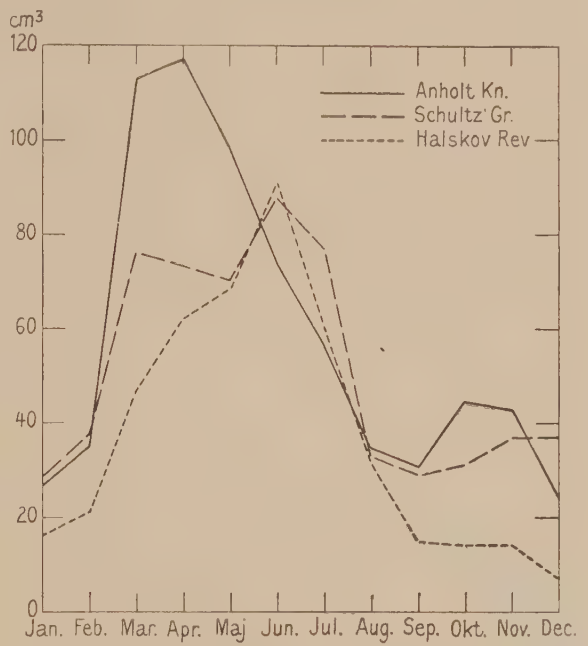

Figure 9. Monthly variation in the amount of plankton determined by hauls from bottom to surface with the Hensen net at the light-vessels of Anholt Knob, Schultz' Grund and Halskov Rev.

the hauls made in the different months of the years 1930—39. As will appear from the graphs there is a considerable rise in the quantity of plankton from January and well into the spring or early summer. The plankton used for this investigation includes all species taken in the Hensen net from diatoms to jelly-fish and not only the plankton eaten by the cod larvae; but generally speaking the food animals of the cod larvae no doubt vary in much the same way as the whole amount of plankton, and so the material may be considered sufficiently reliable for the use made of it. However, attention should be called to the fallability implied in the fact that the filtration power of the net changes somewhat with the different species of organisms contained in the water.

It appears from the graphs that in January the quantities of plankton are only 15—25 cm.^{3} per 1 haul while in March—May we find quantities of 50—100 cm.^{3}, or about 4 times as much. To the hatching cod larvae (mostly in March of the beginning of April) it is of vital importance that the development in mass of the plankton during the time after January takes place so rapidly, that the quantity of plankton during the hatching time is sufficient for the nutrition of the larvae recently hatched. If this quantity is large, the growth of the larvae is more assured than when it is small.

In fact, a comparison of the quantity of plankton in winter and early spring with the amount of cod larvae in April—May shows the existence of a connexion between these two factors. The following table gives the correlations between the amounts of plankton (cm.^{3} in mean of hauls with the Hensen net from bottom to surface in the different months) and the amounts of larvae in April—May (number in the ring-trawl per 30 minutes) for the years 1930—39:

Larvae, Belt Sea—quantity of plankton, Halskov Rev L.-V.

January	$+0.869$	± 0.077
February	$+0.668$	± 0.175
March	$+0.716$	± 0.154
April	$\div 0.031$	± 0.301
May	$\div 0.046$	± 0.301

Thus there is here a very distinct positive correlation for the months of January, February and March; for April and May, however, the correlation is so small, that it is quite insignificant. For the Kattegat the following corresponding correlations were found:

Larvae, northern + southern Kattegat—quantity of plankton, Anholt Knob L.-V.

January	$+0.763$	± 0.132
February	$+0.887$	± 0.067
March	$+0.776$	± 0.126
April	$\div 0.129$	± 0.296
May	$\div 0.403$	± 0.252

Here, then, we find the same state of things: a distinct positive correlation for January, February and March and no correlation of importance for April and May.

A corresponding calculation for the quantity of plankton at the Schultz' Grund L.-v. and the amount of larvae in the southern Kattegat gives the following correlations:

Larvae, southern Kattegat—quantity of plankton, Schultz' Grund L.-V.

January	$+0.791$	± 0.118
February	$+0.723$	± 0.151
March	$+0.091$	± 0.314
April	$+0.012$	± 0.301
May	$\div 0.214$	± 0.287

Like for the two other light-vessels there is here a distinct positive correlation for January and February, but not for March, and there is likewise no correlation of importance for April and May.

A calculation of the corresponding correlation between the amount of larvae in all these waters (northern and southern Kattegat + Belt Sea) and the quantity of plankton at the three light-vessels in one gives the following result:

Number of larvae, north. + south. Kattegat + Belt Sea + quantity of plankton at Halskov Rev, Schultz' Grund and Anholt Knob.

January	$+0.925$	± 0.046
February	$+0.809$	± 0.109
March	$+0.782$	± 0.123
April	$\div 0.034$	± 0.301
May	$\div 0.199$	± 0.289

The found positive correlations for January, February and March are very high, being nearly 7—10 times as great as their mean errors, so there can hardly be any doubt that a connexion exists between the quantity of plankton during the first three months of the year and the amount of cod larvae found in March and April. Most likely this connexion must be explained by the cod larvae living on the plankton, so that ample quantities offer good, and small quantities of plankton poor conditions of nutrition to the larvae. In this connexion it might seem strange that a similar connexion should not exist between the amount of larvae and the quantity of plankton in April and May, for also in these two months the cod larvae live on planktonic animals. The lack of such a connexion can be explained partly by the fact that the quantity of plankton in these months, even when it is small, is always great enough for the nutrition of the lar-

vae, partly by the fact that a great deal of the plankton taken in the Hensen net in these months will not serve as food for the larvae. The tiny larvae principally live on the smaller planktonic animals (copepods and their young, nauplii and copepodid stages). Part of these food animals will undoubtedly pass through the rather wide mesh of the Hensen net. Simultaneously with the hauls with Hensen net, however, hauls were made from the same light-vessels with much finer plankton nets which retain all these small animals. The material from the fine plankton net of the Anholt Knob Light-vessel was examined by E. Steemann Nielsen (1940)[1]) for the months of December—February in the years 1930—38; Dr. Steemann Nielsen further placed the corresponding material for 1939 at my disposal. A comparison between the amount of larvae in the Kattegat (north. + south.) in April—May and the quantity of fine plankton at the Anholt Knob Light-vessel in January and February shows that there is some connexion between these two factors, the following correlation being found:

$$r = + 0.448 \qquad \sigma_r \pm 0.253$$

If, however, we calculate the correlation for that period of the winter alone in which the quantity of plankton is smallest, from the beginning of January to the middle of February, we get a considerably greater positive correlation:

$$r = + 0.687 \qquad \sigma_r = \pm 0.167$$

The fact that the amount of larvae is connected with the amount of plankton in the months of January—March, first and foremost during the first part of this period, seems to show that it is of special importance to the larvae that there is an abundance of plankton during their very first time of life when they are recently hatched, in other words during the time immediately after they have used the amount of nourishment found in their yolk-sac. Accordingly, the critical stage in the life of the cod larvae occurs a few days after the hatching.

According to E. Steemann Nielsen (1940) the quantity of plankton in January—February (determined by hauls with the fine-meshed plankton net) in the first line depends on the quantity of light or rather on the quantity of light penetrating into the water. This quantity again depends on several factors, firstly on the number of days with bright weather (sunshine), secondly on days of quiet weather because more light goes through a calm surface, and thirdly on the temperature because a surface covered with ice (which in most cases also means covered with snow) does not by far admit so much light to the water layers as an open surface. In mild winters with much bright and calm weather there are thus good possibilities for the development of the plankton on which the cod larvae are living during the first difficult period of their life. After such winters we may therefore expect to find a large stock of larvae while on the other hand icy and very stormy winters with overcast skies will offer poor conditions to the plankton and hence result in a small amount of larvae.

As stated on page 19 there is a distinct positive correlation between the temperature of the lower water layers in April—May and the amount of larvae taken in the same months. But this correlation cannot be explained directly by the connexion between the amounts of larvae and plankton because these factors showed a positive correlation for the months of January—March only and not for the very months of April—May when the connexion was established between the temperature and the amount of larvae. It should be remembered, however, that the plankton taken with the Hensen net in April and May to a great extent include species playing no part in the food of the cod larvae: certain diatoms (for instance *Rhizosolenia* and *Chætoceras* species) show a distinct maximum in the very months of April and May (C. H. Ostenfeld, 1913)[1], and the same months show large occurrences of young of our two big jelly-fishes *Cyanea capillata* and *Aurelia aurita*; many small medusae, too, have their maximum in spring. The occurrence in mass of these species may easily conceal possible fluctuations in the quantities of the species principally constituting the food of the cod larvae, viz. the copepods and

[1]) Steemann Nielsen, E.: Die Produktionsbedingungen des Phytoplanktons im Übergangsgebiet zwischen der Nord- und Ostsee. Medd. Komm. f. Danmarks Fiskeri- og Havunders., Ser. Plankton, Bd. III, 4. 1940.

[1]) C. H. Ostenfeld: Phytoplankton og Protozoer. De danske Farvandes Plankton i Aarene 1898—1901. Kgl. Danske Vidensk. Selsk. Skr., 7. Rk. Nat. og Math. Afd. IX, 2. 1913.

their young. It is therefore just possible that the latter in year pre-eminently showing high temperatures in spring are much more frequent than in years with comparatively low temperatures though their fluctuations of quantity cannot come into expression by a determination of the fluctuations in the total quantity of plankton by means of the Hensen net.

That high temperatures of the lower water layers in spring are favourable to the larvae further appears from the fact that the growth of the cod larvae is particularly rapid in years with high temperatures: this will be seen from the following correlations between the growth rate of the larvae (determined as the size of the percentage deviation from the mean length found for April—May)[1]) and the temperature at 20 m. depth:

Growth of larvae, Belt Sea—temperature at 20 m. depth, Halskov Rev L.-V. 1923-39, 17 years.

January	+ 0.413	± 0.202
February	+ 0.530	± 0.175
March	+ 0.651	± 0.141
April	+ 0.603	± 0.155
May	+ 0.752	± 0.106

Growth of larvae, south. Kattegat (K_{2+3})—temperature 20 m., Schultz' Gr. L.-V. 1923-39, 16 years.

January	+ 0.217	± 0.244
February	+ 0.160	± 0.263
March	+ 0.017	± 0.250
April	+ 0.521	± 0.182
May	+ 0.655	± 0.143

For the Belt Sea there is here a distinct and safe positive correlation for the time February—May and for the southern Kattegat a corresponding correlation for April and May, in the first line, that is, for the months in which a positive correlation was also found between the amount of larvae and the temperature.

A similar correspondence exists between quantity of plankton in the Hensen net and the growth of the larvae; this appears from the following correlations:

[1]) As the material of larvae in the individual years has been fished at somewhat different times within the months of April and May, it has been divided into 10-days' periods and the mean length calculated for each of these periods. For each period the average length is calculated for all years in one; the positive or negative deviation of each 10-days' period from the average length is calculated in percentage of the latter. The mean figure of the percentages calculated for each year thus represent the growth rate of the larvae in the year in question and is used for the calculation of correlation.

Growth of larvae, Belt Sea—quantity of plankton Hensen net, Halskov Rev 1930-39, 10 years:

January	+ 0.505	± 0.233
February	+ 0.416	± 0.258
March	+ 0.551	± 0.216
April	+ 0.224	± 0.288
May	+ 0.119	± 0.308

Growth of larvae, central and southern Kattegat ($K_2 + K_3$)—quantity of plankton, Hensen net, Anholt Knob and Schultz' Grund L.-V.s 1930-39, 10 years:

January	+ 0.779	± 0.124
February	+ 0.709	± 0.157
March	+ 0.715	± 0.155
April	+ 0.354	± 0.263
May	+ 0.095	± 0.298

Here, then, there is a distinct positive correlation for the months of January, February and March, but only quite an insignificant correlation for April and May.

4. Survey.

The distinct positive correlations given above, partly between the number, partly between the growth of the larvae on one side and the quantity of plankton in the months of January—March on the other show that the thriving of the cod larvae to a high degree depends on the thriving of the plankton, more especially on the earliness at which the plankton begins to develop. The larvae are favoured by so early a development of the plankton, that a large quantity of plankton has appeared at the time when the larvae are hatched or immediately after when the larvae themselves begin to search for food. That no positive correlation was found between the quantity of plankton in April and May and the amount of larvae of course does not mean that the larvae are not dependent on the quantity of plankton in these months, but rather that the plankton of these months as mentioned is principally composed of species that are not utilized by the larvae, and that the changes in the quantities of these species of plankton therefore easily conceal the fluctuation of the plankton (copepods) that is preferred by the cod larvae.

The fact that a distinct positive correlation is found between the temperature of the lower water layers in April—May and the amount of larvae gives reason for the belief that the quantity of plankton used by the larvae, the copepod plankton,

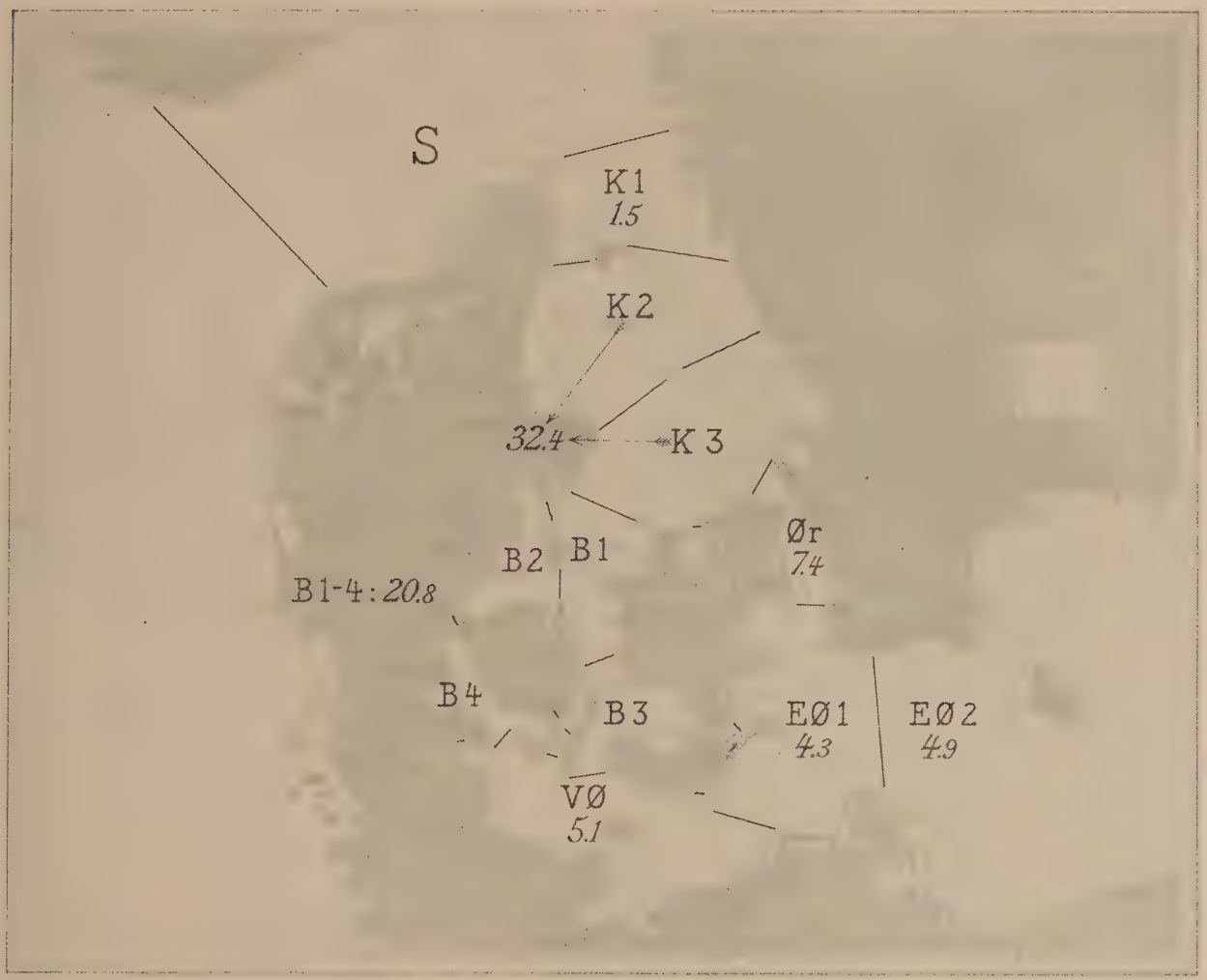

Figure 10. Map of the Danish waters showing the division into areas that has been used for the calculation of the amount of cod fished in the eel-seine. The figures given on the map denote the mean numbers of cod of the 0-Gr. caught per 30 minutes with the eel-seine in different areas of water in the years 1923—39.

depends on the temperature of the sea-water. As long as no investigations have been carried out in Danish waters concerning the conditions of the development of the copepod plankton in early spring, this question can be pursued no further, and we must be content to establish that the amount of cod larvae depends partly on the development of the plankton in late winter and early spring, partly on the temperature of the lower layers of water in April and May.

III. On the influence of the fluctuations in the amount of larvae on the size of the cod population.

1. Fluctuations in the amount of growing-up cod.

On the previous pages it has been shown that the amount of cod larvae in Danish waters is subject to great fluctuations from year to year and that these fluctuations may be traced to changes partly in the temperature of the sea-water at the time when the larvae occur, partly in the quantity of plankton in late winter and early spring.

In the following we will examine whether the fluctuations in the amount of larvae are followed by corresponding fluctuations in the amount of growing-up and of marketable cod, *i. e.* whether

these fluctuations affect the fishery and whether, by following the annual fluctuations in the amount of larvae, we shall be able to forecast the yield of the cod fishery some years in advance.

In order to elucidate this question we will compare the amount of larvae in spring with the amount of (1) the about 6 months old brood in the same summer (0-Gr.), (2) the 1—1$^1/_2$ year old cod (I-Gr.) of the following summer, (3) the 2—2$^1/_2$ years old cod (II-Gr.) of two summers later and (4) the 3—3$^1/_2$ years old cod (III-Gr.) of still another summer later; in other words a comparison between the numbers of individuals of different age-groups of the same year-class. Finally, a direct comparison will be made between the amount of larvae and the catch yield three years later (on the assumption that most of the cod taken in our inner waters are caught at an age between 3 and 4 years).

The calculation of the frequency of the age groups 0—III is based on the results of the fishings with the eel-seine made by the Biological Station in the Danish waters from the Skagerak to the Baltic in the years between 1923 and 1939 (after September 1st 1939 no fishing experiments have been carried out with the eel-seine on account of the war situation). The eel-seine is a fine-meshed trawl without arms and fitted with a chock; its mouth is about 3.5 m. broad and 0.9 m. high, the length about 9 m. The mesh is 15—18 mm. square. The trawl is extended by means of boards, the lines between trawl and boards having a length of 20 m.; the lower lines have tufts of bast. The towing bridle is 40 m. long. When the seine is used on particularly hard bottom (sand), more weight (lead) is fixed to the foot-rope than on soft bottom. The gear is towed at a rate of 1—1.5 naut. mile per hour. During a haul of 30 minutes boards, bast lines and foot-rope sweep an area of about 25 000 m^2, the foot-rope alone about 4 000 m^2.

In Table 3 we find the mean numbers of the 4 youngest year-classes caught per 30 minutes with the eel-seine in the different areas (cp. Figure 10) during the years 1923—39. In the case of the 0-Gr. only hauls made after June 1st were included because the brood of the year do not begin to appear in the eel-seine until June. The areas show rather great differences in the density of the brood: by far the densest stock of 0-Gr. fish is found in the central

Table 3. Numbers of cod of the age groups 0—III-Gr. caught in the eel-seine per 30 minutes in 1923-39. Heavy type denotes the numbers of cod, common type the numbers of stations. For the 0-Gr. only stations worked after 1st June are included.

Age group	0		I		II	III
The northern Kattegat, K_1:						
1923	..		..		..	..
1924	..		..		..	..
1925	**2.3**	3	**1.3**	3	**0.7**	**0**
1926	**0**	6	**5.0**	6	**3.0**	**0.3**
1927	**1.1**	22	**0.3**	22	**1.0**	**0.1**
1928	**8.0**	25	**4.0**	25	**0**	**0**
1929	**3.1**	25	**7.0**	27	**0.9**	**0**
1930	**0**	15	**0.1**	15	**0.1**	**0**
1931	**0.1**	31	**2.7**	32	**0.3**	**0.4**
1932	**0.9**	29	**0.8**	30	**2.7**	**1.5**
1933	**0.3**	19	**3.3**	28	**0.7**	**0.3**
1934	**0**	14	**1.2**	14	**1.6**	**0**
1935	**1.6**	31	**1.2**	31	**0.1**	**0.03**
1936	**0**	13	**3.7**	13	**0.5**	**0**
1937	**0.4**	23	**2.7**	23	**0.6**	**0.1**
1938	**3.1**	37	**2.1**	37	**0.1**	**0**
1939	..		..		..	..
The southern Kattegat, K_{2+3}:						
1923	**24.0**	7	**3.0**	7	**7.0**	**3.0**
1924	**0.5**	4	**35.1**	7	**1.6**	**2.1**
1925	**207**	3	**16.4**	7	**0.9**	**0**
1926	**0.2**	15	**15.7**	22	**2.5**	**1.2**
1927	**28.8**	9	**1.0**	46	**2.2**	**0.1**
1928	**54.6**	16	**5.3**	17	**0.2**	**0.2**
1929	**5.6**	40	**7.0**	41	**1.1**	**0**
1930	**60.1**	21	**1.9**	23	**0.6**	**0.7**
1931	**4.4**	31	**4.6**	31	**2.5**	**0.8**
1932	**107.7**	7	**4.4**	11	**2.0**	**0**
1933	**0.1**	18	**16.6**	26	**1.3**	**0.6**
1934	**0.9**	39	**1.0**	40	**4.6**	**0.5**
1935	**0.5**	24	**2.0**	27	**0.7**	**0.8**
1936	**0.1**	19	**7.6**	21	**1.2**	**0.4**
1937	**1.0**	23	**0.3**	31	**0.6**	**0.03**
1938	**14.2**	23	**10.5**	24	**0.04**	**0.04**
1939	**0.3**	9	**4.9**	16	**0.9**	**0**
The Sound, Ør:						
1923	**17.0**	14	**0**	14	**11.0**	**2.0**
1924	**0.2**	10	**12.0**	13	**2.2**	**17.0**
1925	**4.6**	9	**2.5**	12	**23.2**	**0.3**
1926	**0.4**	11	**22.7**	11	**7.8**	**22.5**
1927	**0**	3	**0**	3	**13.3**	**1.7**
1928	..		..		..	..
1929	**0**	9	**6.2**	10	**5.9**	**0.7**
1930	..		..		..	..
1931	**2.0**	2	**48.3**	3	**6.7**	**8.0**
1932	**16.1**	10	**1.6**	10	**17.8**	**1.7**
1933	**0.2**	8	**15.9**	9	**2.8**	**16.3**
1934	**0.5**	12	**4.5**	12	**28.8**	**1.0**
1935	**7.5**	2	**4.8**	5	**4.2**	**2.8**
1936	**1.6**	5	**5.6**	8	**8.0**	**4.1**

Table 3 (continued).

Age group	0	I	II	III
1937	5.0 5	1.9 8	43.5	8.1
1938	43.9 9	4.4 15	0.9	1.1
1939	2.0 1	18.0 5	7.4	0.6
The Belt Sea, B_{1+4}:				
1923	113.0 33	1.0 36	6.0	1.0
1924	4.0 23	54.0 42	2.0	2.0
1925	40.2 2	4.0 36	18.0	0.3
1926	0.8 32	45.0 67	5.0	10.0
1927	6.0 32	0.1 41	6.1	0.6
1928	14.0 59	7.1 89	0.6	4.2
1929	12.3 40	9.1 47	3.3	0
1930	7.2 61	5.0 64	6.0	1.1
1931	0.7 75	4.9 90	2.8	1.3
1932	38.2 69	7.3 92	7.3	1.1
1933	1.8 29	16.2 57	2.9	5.1
1934	4.5 44	1.3 56	6.4	4.0
1935	5.8 20	2.8 57	1.3	4.3
1936	4.0 49	3.5 60	1.4	0.5
1937	39.7 11	0.7 56	0.2	0.4
1938	51.4 50	4.8 93	0.2	0.2
1939	4.2 37	4.3 64	4.5	0.1
The western Baltic, V Ø:				
1923	..	..	..	..
1924	..	3.0 1	0	0
1925	0 1	3.0 2	2.0	0
1926	..	..	..	..
1927	42.4 5	0.2 5	2.6	0.6
1928	6.2 10	15.5 10	0.1	4.9
1929	0 1	0 1	0	0
1930	3.6 15	5.0 15	0.2	0.1
1931	3.7 3	2.0 7	5.0	1.0
1932	1.1 10	0.1 10	4.7	2.4
1933	0 6	3.7 6	1.8	6.2
1934	..	0 1	1.0	1.0
1935	..	0 1	0	0
1936	4.0 3	5.7 3	0	0.3
1937	0 1	0.6 5	0.4	0.2
1938	0 2	14.2 9	0.2	0.2
1939	0 5	2.9 9	1.3	0.2
The western part of the Baltic proper, E $Ø_1$:				
1923	21.6 8	0.3 8	0	0.3
1924	0.1 17	10.0 17	0.2	0.3
1925	7.1 19	0.6 22	2.0	0
1926	0.2 21	7.5 21	0.2	1.2
1927	6.4 21	0.2 21	1.9	0.2
1928	9.6 8	0.7 24	0.2	1.1
1929	1.7 3	1.0 3	0	0
1930	7.1 21	0.8 21	1.5	0.1
1931	..	..	..	..
1932	0 5	0 6	1.2	0.5
1933	0 13	6.3 13	0.2	10.9
1934	32.7 15	3.1 15	13.1	1.5
1935	0 3	0.2 9	0	0
1936	5.2 5	3.9 9	3.4	1.2
1937	..	0.9 12	0	0.3
1938	..	10.5 8	0	0
1939	0.9 7	1.1 9	4.2	0.7
The eastern part of the Baltic proper, E $Ø_2$:				
1923	..	..	..	..
1924	..	..	..	..
1925	..	5.0 7	0	2.0
1926	0.1 12	15.0 12	3.0	2.0
1927	5.0 27	1.3 27	0.2	0.3
1928	8.3 32	0.8 32	0.2	0.4
1929	..	..	..	..
1930	..	..	..	..
1931	0.2 13	2.7 13	0.2	0.1
1932	0.1 10	0.7 10	11.6	0.7
1933	0.2 13	3.0 13	0.5	6.2
1934	26.4 15	2.7 14	0.3	0.4
1935	0.3 19	3.2 19	0.9	1.2
1936	0.1 19	1.6 19	0.3	0.2
1937	0.9 22	7.3 22	0.7	3.4
1938	16.7 18	5.6 18	0.8	0.6
1939	0.1 22	3.2 22	2.9	1.1

and southern Kattegat and in the Belt Sea (cp. Figure 10) where the averages taken in the years 1923—39 are 32 and 21 per 30 minutes, respectively; in the Baltic and the Sound the averages were between 4 and 7, and in the northern Kattegat only 1.5.

A look at the table will show that within the different age groups there are considerable fluctuations of amount from year to year. In the southern Kattegat, for instance, we see that of the 0-Gr. 24 individuals were taken per 30 minutes in 1923, only 0.5 in 1924, but no less than 207 in 1925. Also in the I-Gr. there are great fluctuations from year to year: in 1923 only 3.0, in 1924 35.1 individuals were taken per 30 minutes. Of the II-Gr. 7.0 individuals were caught per 30 minutes in 1923, but only 1.6 in 1924. Similar fluctuations from year to year are found in the III-Gr. The numbers of cod of older age groups are rather small in the catches. In the years 1923—39 the mean numbers of the different age groups taken per 30 minutes with the eel-seine in the southern Kattegat (K_{2+3}), the Belt Sea and the Sound collectively were as follows:

0-Gr.	20	individuals
I-Gr.	9	—
II-Gr.	5.6	—
III-Gr.	2.6	—

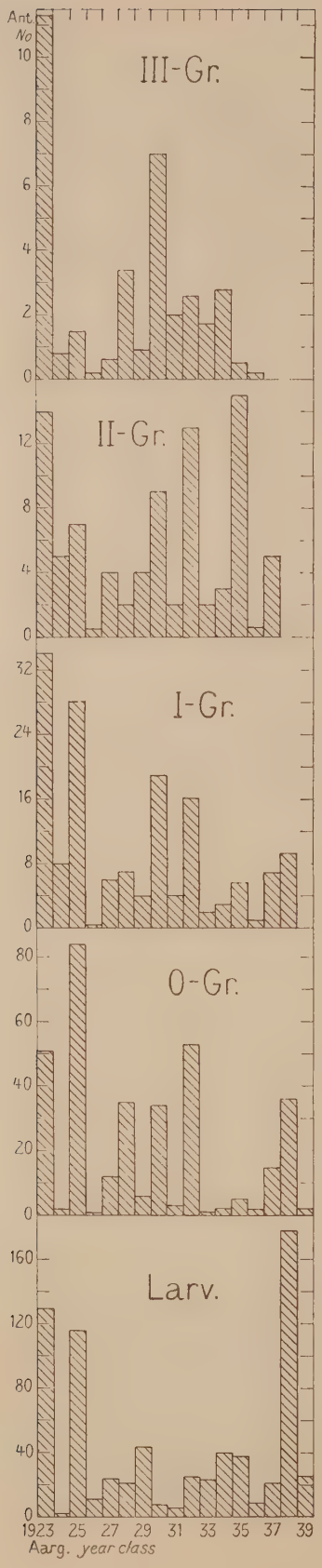

Figure 11. Comparison of catches of larvae per 30 minutes in the ring-trawl with catches of individuals of the 0-, I-, II- and III-Gr.s per 30 minutes in the eel-seine in the central and southern Kattegat (K_{2+3}), the Belt Sea (B_{1-4}) and the Sound (Ør) in the years 1923—39.

Thus the numbers diminished by nearly half the individuals from one age-group to the other. This decrease is due partly to the fact that there are fewer older and bigger fish than younger and smaller ones on account of the natural mortality and the effects of the fishery, partly to the fact that the fine-meshed eel-seine take comparatively more of the smaller than of the bigger fish.

2. The connexion between fluctuations in the amount of larvae and growing-up cod.

The question now arises whether there is a connexion between the annual fluctuations in the amounts of larvae and of growing-up cod. Figure 11 shows a comparison between catches of larvae in the ring-trawl and of individuals of the 0-, I-, II- and III-Gr.s in the eel-seine per 30 minutes in the southern Kattegat (K_{2+3}), the Belt Sea (B_{1-4}) and the Sound (Ør) on the basis of the figures of Table 3. On the whole there is a good correspondence between the catches: the year-classes that are rich as larvae mostly turn out to be rich also as 0-, I-, II- and III-Gr., for instance the 1923, 1925 and 1938 year-classes, while the poor year-classes of larvae are also poor as 0-, I-, II- and III-Gr., for instance the 1924, 1926, 1931 and 1936 year-classes. For a few year-classes, however, there is no correspondence: in 1930 there were but few larvae, but still this year-class became numerous as 0-Gr. and later on as older fish. A possible explanation of this lack of correspondence is an influx of con- siderable amounts of 0-Gr. fish into our inner waters from without in the course of the summer, for during the time between May and October there were very high salinities and, accordingly, a rapid inflow of salt water as will be seen from the following figures:

Salinity at 28 m. depth at the Anholt Knob:

	May	June	July	Aug.	Sep.	Oct.
normal	33.1	32.8	32.3	31.9	31.8	32.2
in 1930	34.5	34.4	33.9	33.6	34.0	33.6
difference (1930 minus normal)	+ 1.4	+ 1.6	+ 1.6	+ 1.7	+ 2.2	+ 1.4

In this connexion it is interesting to note that the year 1930 was conspicuous by an extensive influx of brood of the rough dab into the Belt Sea and the western Baltic (P. F. Meyer, 1935 and 1937 and Erik M. Poulsen, 1937)[1]).

The connexion between the amount of larvae on one side and the amounts of 0-Gr. and older age groups on the other appears from the following correlations from the said 3 waters (the southern Kattegat, K_{2+3}, the Belt Sea, B_{1-4} and the Sound, Ør) for the years 1923—39:

Larvae per 30 minutes in ring-trawl, April + May:

0-Gr. Eel-seine per 30 min., June—Oct.	+ 0.537	± 0.173
I-Gr. Eel-seine, April—Oct. 1 year later	+ 0.552	± 0.174
II-Gr. Eel-seine, April—Oct. 2 years later	+ 0.481	± 0.199
III.Gr. Eel-seine, Apr.—Oct. 3 years later	+ 0.506	± 0.199

The correlation is seen to be distinctly positive and nearly or a little more than 3 times its mean error. For the individual waters the following correlations were found:

[1]) Paul-Friedrich Meyer: Drepanopsetta-Besiedlung der Westlichen Ostsee, and Erik M. Poulsen: Fluctuations in the Regional Distribution of certain Fish-Stocks within the Transition Area during recent years (1923—35). Rapp. et Proc. Verb. d. Cons. Int. p. l'expl. de la mer. CII. 1937.

Northern Kattegat (K_1) larvae:

0-Gr.	+ 0.702	± 0.158	10 years
I-Gr.	+ 0.658	± 0.172	11 —
II-Gr.	÷ 0.316	± 0.273	11 —
III-Gr.	+ 0.026	± 0.312	10 —

Southern Kattegat (K_{2+3}) larvae:

0-Gr.	+ 0.108	± 0.247	16 years
I-Gr.	+ 0.167	± 0.251	15 —
II-Gr.	+ 0.402	± 0.224	14 —
III-Gr.	+ 0.332	± 0.247	13 —

The Sound (Ør) larvae:

0-Gr.	+ 0.567	± 0.189	13 years
I-Gr.	+ 0.407	± 0.253	11 —
II-Gr.	+ 0.075	± 0.311	10 —
III-Gr.	+ 0.868	± 0.082	9 —

The Belt Sea (B_{1-4}) larvae:

0-Gr.	+ 0.830	± 0.074	18 years
I-Gr.	+ 0.616	± 0.151	17 —
II-Gr.	+ 0.736	± 0.115	16 —
III-Gr.	+ 0.688	± 0.135	15 —

The western Baltic (V Ø) larvae:

0-Gr.	+ 0.463	± 0.240	11 years
I-Gr.	+ 0.299	± 0.280	9 —

not continued on account of the insufficiency of the material.

Western part of the Baltic proper (E $Ø_1$) larvae:

0-Gr.	+ 0.498	± 0.217	12 years
I-Gr.	+ 0.281	± 0.291	10 —
II-Gr.	÷ 0.290	± 0.295	10 —
III-Gr.	÷ 0.369	± 0.288	9 —

For the Belt Sea, the water from which we have the most extensive investigations on larval and older stages, there is a very distinct connexion between the fluctuations in the amounts of larvae and of the older stages (0—III-Gr.). In the other waters the connexion is not always so distinct. Obviously the material from these waters is not sufficient for a safe determination of the connexion. But the great positive correlations found for the Belt Sea tell us that the amount of larvae decidedly influence the quantity of older cod in our waters, so that at any rate the Belt Sea investigations of the Biological Station can be used as a basis if, from the larval stage of a certain year-class, we want to forecast the size of the stock of cod about 2—4 years later.

As might be expected there is generally a somewhat distincter correlation between the 0-Gr. and the older age groups. The following correlations have been found for the individual waters:

Northern Kattegat:

0-Gr.—I-Gr.	+ 0.712	± 0.137	13 years
0-Gr.—II-Gr.	÷ 0.216	± 0.276	12 —
0-Gr.—III-Gr.	+ 0.348	± 0.265	11 —

Southern Kattegat:

0-Gr.—I-Gr.	+ 0.384	± 0.213	16 years
0-Gr.—II-Gr.	+ 0.585	± 0.170	15 —
0-Gr.—III-Gr.	+ 0.359	± 0.233	14 —

The Sound:

0-Gr.—I-Gr.	+ 0.887	± 0.064	11 years
0-Gr.—II-Gr.	+ 0.567	± 0.204	11 —
0-Gr.—III-Gr.	+ 0.497	± 0.251	9 —

The Belt Sea:

0-Gr.—I-Gr.	+ 0.820	± 0.073	20 years
0-Gr.—II-Gr.	+ 0.733	± 0.105	19 —
0-Gr.—III-Gr.	+ 0.700	± 0.121	18 —

Western Baltic:

0-Gr.—I-Gr.	+ 0.619	± 0.195	10 years

Western part of Baltic proper:

0-Gr.[1])—I-Gr.	+ 0.368	± 0.288	8 years
0-Gr.—II-Gr.	+ 0.791	± 0.125	9 —
0-Gr.—III-Gr.	÷ 0.224	± 0.316	9 —

Judging by these calculations there is hardly any doubt that the amount of cod of the I—III groups depends on the amount of the appearing fry.

3. On the dependence of the catch yield on the amount of the young.

By far the greater part of the cod of the II- and III-Gr.s and some of the I-Gr. are above the minimum size-limit, 27.5 cm., as it was fixed in the Fisheries Act of 1931, so that they belong to the stock of marketable fish, which, however, also includes the older age groups. So few of these older and bigger cod are taken in the eel-seine, that we cannot use these catches for an examination of the question whether a connexion exists between the fluctuations of the amount of the brood and the numbers of these older fish. In order to examine whether the amount of the brood to any important degree affects the size of the stock of the marketable fish as a whole we may compare the amount of the brood (larvae—0-Gr.) with the catch yield after an adequate series of years. But here we meet with the difficulty that the marketable fish include several age groups and that the stock of marketable fish

[1]) Only catches after 1. July are included.

Table 4. Yields in tons of the danish cod fishery in the years 1920—1940. From "Fiskeriberetningen".

Year	The North Sea[1])	The Skagerak	The Limfjord	The Kattegat	The Sound	The Belt Sea	The Western Baltic	The Baltic proper	Total	Øre/kg
1920.....	1 359	1 316	738	4 822	1 227	6 575	331	944	17 358	42
1921.....	1 045	1 276	772	4 073	1 144	6 010	323	743	17 423	33
1922.....	824	1 222	860	4 412	1 115	5 056	272	639	14 759	24
1923.....	1 198	1 473	246	5 633	1 375	5 793	252	663	16 742	26
1924.....	1 625	1 097	94	5 543	1 156	5 064	348	1 021	16 163	33
1925.....	2 080	1 198	88	5 778	1 315	6 110	368	1 101	18 301	30
1926.....	2 176	1 342	50	6 102	1 351	7 542	593	1 343	20 761	21
1927.....	3 543	2 173	73	6 092	1 531	7 576	460	1 174	22 823	18
1928.....	3 102	2 197	47	6 235	1 492	8 801	681	1 226	23 886	19
1929.....	2 513	1 799	223	5 260	1 148	6 245	430	749	18 475	24
1930.....	3 060	1 651	185	5 478	1 580	7 632	526	892	21 191	23
1931.....	3 964	2 129	136	6 160	1 489	7 643	495	745	22 198	21
1932.....	4 395	1 888	77	4 395	1 602	7 374	598	702	21 576	20
1933.....	6 020	1 465	124	4 248	1 314	7 244	576	978	22 513	21
1934.....	4 637	1 954	92	3 743	1 383	8 438	519	1 438	22 397	21
1935.....	3 366	1 533	91	3 782	1 476	8 273	647	1 701	21 065	22
1936.....	2 902	1 044	64	3 725	1 177	7 168	1 040	1 900	19 208	22
1937.....	3 340	990	46	4 134	1 076	6 683	784	1 908	19 057	21
1938.....	3 353	1 434	70	3 160	1 319	5 758	669	3 452	19 298	24
1939.....	5 302	1 481	160	2 738	1 338	6 199	967	3 748	21 933	24
1940.....	3 634	1 454	346	3 868	1 590	7 009	1 376	6 336	25 614	35
1941.....	6 287	1 597	265	6 130	1 772	8 267	1 619	11 038	36 976	..

[1]) Catches landed in foreign harbours not included.

will not be composed of the same proportion of age groups in the different years. In this way a moment of uncertainty enters into the calculation, which will complicate the demonstration of a connexion between the amounts of the brood and of the marketable fish. Add to this that the fishery does not every year remove the same percentage of the stock of marketable fish present. In years with a small stock of marketable fish the fishery will take away a comparatively great part, being more intense in order to meet the demands of the market; in years with a larger stock of marketable fish a smaller percentage will be taken because the fishing intensity decreases on account of the fact that the purchasing power of the market will not be much greater than in years with a limited stock.

Table 4 gives the catch yields of the cod fishery in our different waters. The fluctuations in the yield of the cod fishery are much smaller than those of the amount of larvae and of individuals of the 0-Gr.: in the Belt Sea the amounts of larvae and 0-Gr. cod vary between quite a few specimens in one year and more than a hundred in another, while the yield of the fishery within the same period (1923—39) only varies between about 5 000 and about 7 000 tons. Figure 5 on p. 14 shows a comparison between the fluctuations in the yield of the fishery and in the amount of larvae in the Belt Sea. We note a certain degree of correspondence between these fluctuations: the two good spawning years of 1923 and 1925 are followed by high catch yields in the years 1926—28, that is to say 3 years later, and the continuous series of the poor of less good brood years 1930—33 are followed by a considerable fall of the yield in 1935—38. After this we find another rise of the yield in 1940 and 1941, apparently a consequence of the very ample occurrence of fry in 1938. Also for all waters within the Skaw collectively we note a connexion between the amount of brood and catch yield: the two good brood years of 1923 and 1925 are followed by a considerable rise in the catch yields of 1926—28, from about 14 000 to about 18 000 tons. The rise occurs 3 years later, *i. e.* at the time when the largest amount of the brood of these years are contained in the catches. After this there is again a long series of years with average

yields (about 14 000 tons) corresponding to the series of rather poor or average brood years 1926—27. In 1938 there is another uncommonly rich brood year; already in 1940, two years later, at a time when considerable quantities of the brood of 1938 can begin to make themselves felt among the marketable fish, there is a considerable rise in the yield, to about 20 000 tons, the yield rising even more abruptly to 29 000 tons in 1941. In other words the good and poor brood years can be traced distinctly in the catch yields. This correspondence between the amount of larvae and the catch yield further appears from a calculation of correlations between catches of larvae in one year and the yield of the cod fishery 3 years later. This time of 3 years has been chosen because the III-Gr. (the 3-year-old fish) is the age group that can be reckoned to constitute the greater part of the catches:

Mean number of larvae per 30 minutes in April + May from all waters within the Skaw correlated with the catch yield of the same waters 3 years later for the years 1923(26)—1938(41): $r = +0.687 \pm 0.132$.

In other words there is a distinct and safe positive correlation between the amount of larvae and the yield of the fishery. If we calculate the corresponding correlation on the assumption that a year-class of brood forms part of the catch yields with equally great portions 3 and 4 years later, we get the figures: $r = +0.516 \pm 0.198$. In this case, too, there is a great positive correlation, though not so great as by an interval of 3 years alone, and its mean error is a little above $^1/_3$ of the correlation.

Judging by these investigations there is a distinct connexion between the amounts of larvae and the yield of the fishery in our waters within the Skaw, and for these areas we may then, basing on the investigations of the Biological Station on the amount of larvae in spring, with a considerable degree of accuracy forecast the possibilities of a good or bad cod fishing about 2—4 years later.

IV. Fluctuations in the yield of the Danish cod fishery in 1920—40.

1. Changes in the extent and the methods of the fishery.

The size of the cod population at the disposal of the fishery depends not only on the quantity of the fry hatched and on its thriving, but also on the extent to which the fishery removes the fry and growing-up cod both below and above the minimum size-limit. Besides on this extent the preying upon the fry and the growing-up cod further depends on the way in which the fishing is carried out; in this field these 20 years have brought about some changes, of which it might be feared that they would cause a deterioration of the stock of cod. Among changes of this kind may be mentioned:

1. the rising pound-net and eel-weel fisheries;
2. the fishing for waste fish and
3. the preparation of fillet of cod.

Within the period 1920—40 the number of pound-nets in all our waters have risen from 3 800 in the years 1920—23 to 5 400 in the years 1937—40 or by more than 40 per cent. The pound-nets take considerable quantities of cod, partly greater fish, but also many small ones, and especially the pound-nets used for eel catching take many small cod below the minimum size-limit. Even if part of the small cod caught in the pound-nets can be liberated again in a sound condition, considerable quantities undoubtedly perish both when the nets are full of fish (or jelly-fish) and when the nets are emptied in long intervals.

The rise in the number of eel-weels has been even more rapid, from 34 000 in the years 1920—23 to 58 000 in 1937—40, a rise of more than 70 per cent. The eel-weels often take considerable quantities of small cod (of the 0- and I-Gr.s), and here, too, only part of them can be liberated in a state so as to be fit to survive.

No figures are available to tell of the amounts of small cod that are caught and spoiled in pound-nets and eel-weels. But at any rate part of these gears are placed along the coasts at depths favoured by the cod fry, and so there is no doubt that the enormous rise in the number of pound-nets and eel-weels during these 20 years have caused considerable damage to our stock of cod.

A restriction of the use of these fishing gears can hardly be effected for the sake of the cod fry, but it should be emphasized that the greatest possible care must be taken when pound-nets and eel-weels

are emptied, so that the cod fry captured are liberated in a state so as to be fit to survive.

The fishery for waste fish—*i. e.* fish used as food for pond fish or in the industry for the manufacture of such products as oil, fish meal and the like—has developed rapidly during recent years. Against this fishery the objection has often been raised that far too much fish fry is spoiled by it. There is no doubt that large amounts of the brood of mackerel, herring and sprat are taken in this fishery, but it appears from the examination into the catches of waste fish made by the Biological Station in the years 1939—41 that only small numbers of the brood of cod occur in these catches: in 254 kg. of waste fish examined there were only 2 kg. of cod, that is to say quite an insignificant portion. In "Fiskeri-Beretningen" (the Fishery Reports) the catch of waste fish is estimated at 7.5 mill. kg. If we reckon 2 kg. of cod for every 250 kg. of waste fish the quantity of cod taken per annum in this fishery amounts to only 60 tons, which is but a neglibigle quantity as compared to the total catch of cod (22 000 tons in 1939). The fact that so small an amount of cod is taken in this fishery is due to the circumstance that it is pursued in somewhat deeper water than that in which the young cod are living (outside a depth of about 20 m.). If, however, this fishery should in future be extended to shallower water, it is to be feared that considerable amounts of young cod will be destroyed.

Like the catching of waste fish the preparation of fillet is a new gain of our fisheries. Only 225 tons of fillet were made in 1931, but in 1937—40 the annual preparation was about 1 300 tons. By far the greater part of the fish used for this manufacture were cod. Broadly speaking there is 60 per cent. of waste in the preparation, which means that about 3 200 tons of living cod are used for the 1300 tons of fillet. This figure is high as compared to the total catch (in 1939 22 000 tons). The cod used for the fillets are principally small cod, and so their number makes up an even more substantial part of the catch. The use of a great part of our stock of cod for the preparation of fillet is of course not very expedient because many cod are fished at a young age and a rather small size. In periods when the stock of growing-up cod in our waters is small the constant great demand for small cod by the fillet factories of course involves some danger to the stock. In view of the best exploitation of our stock of cod it would therefore undoubtedly be expedient to use somewhat bigger cod for the preparation of fillet than has hitherto been the case.

2. Fluctuations in the size of the stock of cod and their dependence partly on the appearance of fry, partly on the fishery.

In connexion with the increasing demands on the cod population of our waters made during recent years on the part of the fishery, among other things through the rising fishery with pound-nets and eel-weels and the use of cod for the preparation of fillet, it is of interest to examine whether the renewal of the stock has been sufficiently extensive to meet these demands.

Figure 12 shows how many individuals of young cod (I-, II- and II-Gr.) were taken per 30 minutes in the eel-seine in the southern and central Kattegat (K_{2+3}) and the Belt Sea (B_{1-4}) in the years 1923—39. With a view to balancing the fact that the eel-seine catches comparatively fewer individuals of the II- and III-Gr.s than of the I-Gr. the catch figures for the II- and III-Gr.s have been multiplied by 2 and 4, respectively, before they were added to the catch figures of the I-Gr. (see p. 27).

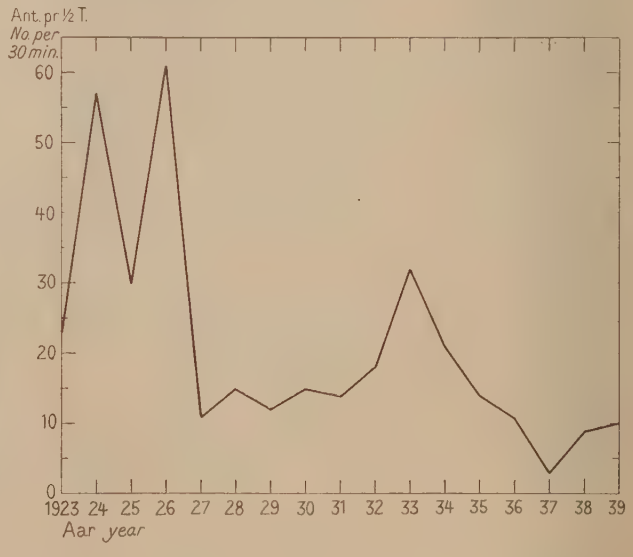

Figure 12. Numbers of young cod (I—III-Gr.) caught per 30 minutes in the eel-seine in the Belt Sea (B_{1-4}) and the central and southern Kattegat (K_{2+3}) in the years 1923—39.

The figure shows that we have had a large stock of young cod in our inner waters in the years 1923—26 (an older, more scanty material shows that this was also the case in the years immediately before), after which we had a series of poor years in 1927—31, a small rise in 1932—33 and 34, another fall in 1935—37 and a beginning rise in 1938—39. No fishings with the eel-seine have been made since 1939, but judging by the heavy catches of cod in our waters in 1940—41 we may take it that the rise in the stock of young cod has continued through these years.

In other words the stock of young cod was decidedly larger at the beginning of the twenties than at the end of the twenties and in the thirties. As mentioned above this is undoubtedly due to the fact that in the years after 1928 we have had a number of poor or barely average brood years. But the large amount of fry appearing in 1938 and the rapid rise in the yield of the cod fishery in 1940—41 show that under good conditions the stock of cod has been able to rise again.

Several things seem to indicate that the stock of cod in the Belt Sea and the southern and central Kattegat in the years about 1934—38 had grown so small, that it could hardly bear the fishery. In the first place the yield of the fishery (Table 4) decreased very rapidly in these years:

Yield of the cod fishery in the Kattegat and the Belt Sea:

Year	Tons
1934	12.181
1935	12.035
1936	10.893
1937	10.817
1938	8.918
1939	8.937
1940	10.877
1941	14.397

In the years 1934—38 the yield had thus fallen from over 12 000 to barely 9 000 tons, a decrease of about 27 per cent.

Secondly, the amount of young cod taken in the fishing experiments decreased rapidly in these years (see Figure 12), from more than 20 per 30 minutes in 1934 (and 32 in 1933) to only 3 in 1937.

Thirdly, a decrease in the amount of cod during these years was also observed by the professional fishermen. It appears from reports from the fishery patrol to the Directorate of Fisheries that from the waters round our islands the demands for cod were hardly met during any part of 1936, and in 1937 and 1938 the fillet factories periodically had to suspend the work on account of the lack of small cod. Undoubtedly the fishery during these years, particularly for small cod, has been unable to meet the demands in spite of its being pursued at least with normal energy.

In the course of 1939 the stock of young cod rose somewhat, partly because the comparatively good 1937 year-class of the Belt Sea (see Table 3) had now passed the minimum size-limit, partly because the very rich 1938 year-class began to pass it in late summer. In "Fiskeri-Beretningen" for 1939 it is stated that in the inner waters there has been noticed the appearance of a stock of cod fit for the preparation of fillet.

It cannot of course be decided to which degree the decrease in the size of the stock of cod in 1933—38 was due to natural causes (poor brood years) or was a consequence of intense fishing. Apparently both causes have acted together, and it seems to be certain that the cod fishery has now become so intense, that the stock decreases considerably on account of the fishing, so that in periods with a small appearance of fry, the latter is not even able to balance the reduction of the stock.

It thus seems that the cod fishery has now grown so intense that, at any rate periodically, it reaches and even passes the limit of what the stock of cod is able to sustain without a deterioration, and so there will in future be every reason for a somewhat greater attention being paid to the question concerning the protection of the stock of cod.

The considerable rise in the yield of the cod fishery in our inner waters in 1938—41 will apparently be followed by a decline during the course of a few years. The rise was undoubtedly due firstly to the extremely large amount of larvae appearing in 1938, secondly, though to a much smaller degree, to the good brood year of the Belt Sea in 1937. The brood of these two year-classes will suffice for the catches of 1940—42; but already in 1943 they will be of much less importance, and if no other good year-classes have appeared later on, some decrease in the cod fishery of our inner waters must be supposed to occur already during 1943.

Unfortunately there is no reason to believe that average, not to speak of very good year-classes are developing in the years 1940—42. Larval investigations have shown that 1939 was rather poor in larvae, and the amount of fry hatched was a little below the normal. We know from the investigations dealt with above that particularly cold springs are unfavourable to the cod fry and that only small amounts of fry use to appear in such springs. The winters of 1939/40, 1940/41 and 1941/42 were all extremely cold, and the spring came late in these years, and so there is every reason to believe that the amounts of fry hatched in these years are considerable below the normal. This again means that there are no good year-classes in our waters to compensate for the rich 1938 year-class, which will nearly be fished out in 1943, and there is hardly any doubt that the stock of cod in the next few years will be rather small and the yield of the cod fishery comparatively low. However, there is a possibility that the forced protection of certain waters during the war will to some extent be able to remedy this calamity.

In the Baltic proper the rise of the yield during recent years has been extremely great, from about 700 tons in 1932 to about 11000 tons in 1942.

The rapid rise of the catch yields in the Baltic has been recorded not only by the Danish cod fishery, but also by those of other Baltic countries. The rise set in nearly at the same time in all countries, in 1932—33. Until 1938 there was an increase from about 2 000 to 8 000 tons in Sweden, from about 1 000 to 3 000 tons in Latvia, from about 200 to about 2 000 tons in Poland and from about 2 000 to about 8 000 tons in Germany.

Unlike the other Danish waters the Baltic thus shows an increase of the cod fishery also in the years before 1938; here, then, the rise cannot primarily be due to the 1938 year-class, at any rate not during the first part of the period of increase. The rapid rise in the Baltic is probably due to the fact that the cod fishery in this water was not intensified

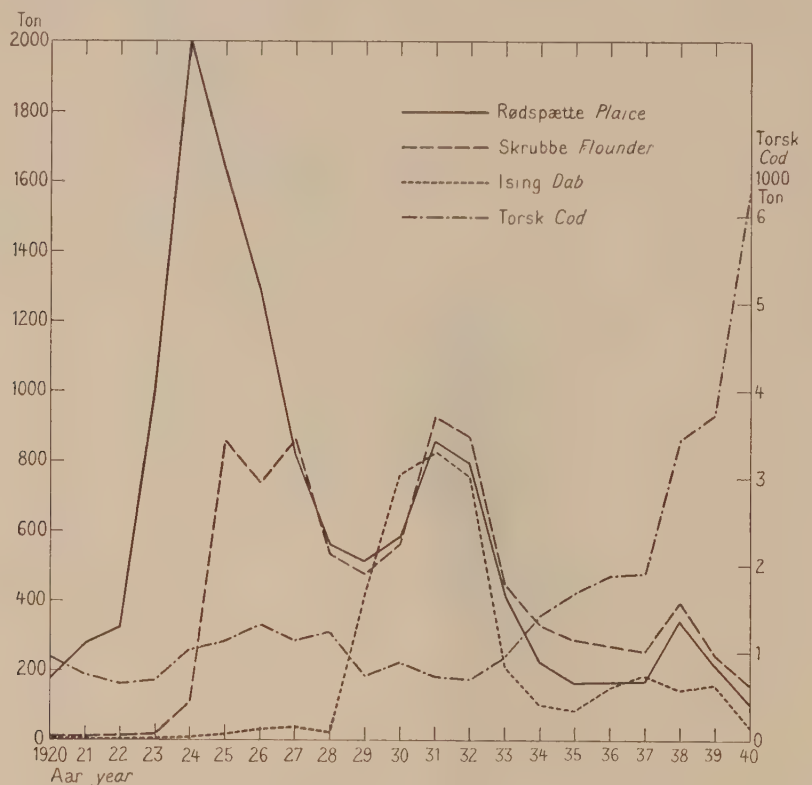

Fig. 13. The yields of the Danish fisheries for cod, plaice, flounder and dab in the Baltic proper in the years 1920—40. Scale for cod to the right, for the other species to the left.

until the stocks of other food fishes had been thinned out to a high degree. The principal food fishes among the bottom fishes of the Baltic are plaice, flounder, dab and cod. Figure 13 shows the fluctuations in the yields of these 4 species between 1920 and 1940. As far as the three flat fish species are concerned the fisheries show the same development. The yield of the plaice fishery rose rapidly in 1923—24 and was still high in 1925—26. In 1927—29 there was a very rapid fall followed by another small rise in 1931—32 (caused by the rich 1928 year-class); since then the yield of the plaice fishery has again been falling rapidly. The flounder fishery shows fairly the same development (cp. Blegvad, 1932)[1]). The rise of the yield did not occur until 1925, after which the catches abated in 1928 and 1929 and rose again in 1931—32 (the 1928 year-class of the flounder was very rich, too). Since 1934 there has been another rapid decline. The yield of the dab fishery did not begin to rise until 1929, *i. e.* at the time when the yield of the plaice and flounder fisheries were very low; in the years 1930—31—32 the catches were very heavy (cp. Erik M. Poulsen, 1938)[2]). In 1933 the yield of this fishery showed another rapid fall and is now very small. In other words the three flat fish fisheries in the Baltic through these 20 years exhibit a rapid rise of the yields followed by a fall of the same rapidity, so that at present nearly the same catches are taken as at the beginning of the twenties. As demonstrated by various authors these fluctuations of the yield in the first line are due to the fact that a fishery was started on a dense, saved-up stock, after which the fishery, when the saved-up stock had been fished out, fell to its former low level; in the second line, and to a much less degree, they are due to annual fluctuations in the amount of fry.

In view of these fluctuations in the catches of plaice, flounder and dab in the Baltic there is every reason to believe that the rapid rise in the yield of the cod fishery of the Baltic in quite a few years will be followed by a decrease of the same rapidity. The rise of the plaice, flounder and dab fisheries did not bring about a constant increment of the yields; no more can we expect the rise in the yield of the cod fishery to be of a permanent character, dependent as it undoubtedly is partly on a saved-up stock, partly—in the case of these recent years—on the prominent brood year of 1938.

Summary.

The present paper deals with an investigation on annual fluctuations in the amount of cod fry in our inner waters, on the causes of such fluctuations and on their effect upon the stock of cod and, consequently, upon the cod fishery.

I. An account has been given on the fluctuations in the amount of cod larvae in the Danish waters within the Skaw in the years 1923—39, based on fishing experiments carried out by the Danish Biological Station and "Kommissionen for Danmarks Fiskeri- og Havundersøgelser". It has been demonstrated that the amount of larvae may vary to an exceedingly high degree from one year to another: in some years the mean catch per 30 minutes' haul with the ring-trawl (2 m. in diameter) was below 10, in others it was above 100. Broadly speaking the years beginning and ending the period 1923—39 were good brood years while the intermediate years were rather poor brood years.

II. It has been attempted to explain the causes in nature leading to these fluctuations. By comparisons between the amount of mother fish (marketable cod) and the amount of eggs (determined by fishings with the Hensen net) on one side and the amount of larvae on the other it has been shown that the amounts of spawning cod and eggs spawned can hardly—and at any rate only in rare cases—be said to have any very considerable effect upon the amount of fry appearing.

A distinct positive correlation has been found between the temperature of the lower water layers in April—May and the found amount of cod larvae:

[1]) H. Blegvad: On the Flounder and the Danish Flounder Fishery in the Baltic. Cons. Int. p. l'expl. de la mer. Rapp. et Proc. Verb. 78.

[2]) Erik M. Poulsen: The Dab in the Danish Waters. Investigations on Stock and Growth. Rep. of the Dan. Biol. Stat. 42.

comparatively high temperatures coincide with particularly large amounts of larvae while comparatively low temperatures are followed by small amounts of larvae.

A distinct connexion has further been established between the amount of larvae in April and May and the quantity of plankton in the months of January, February and March, and it has been stated that this connexion must be due to the fact that the thriving of the larvae to a very considerable degree depends on the quantity of plankton being large enough for the nutrition of the larvae during the first tiny stage of their life in early spring.

III. It has been demonstrated that a distinct accordance exists between the annual fluctuations in the amount of larvae and corresponding fluctuations in the amount of growing-up cod, in other words that the frequency of a year-class and, accordingly, its effect on the size of the stock of cod is determined already at the larval stage. Besides, a distinct connexion has been found between the fluctuations of the amount of larvae and of the yield of the fishery, so that it is possible, from investigations on the amount of larvae, with a high degree of accuracy to forecast the possibilities of the cod fishery about 2—4 years later.

IV. The fluctuations in the yield of the Danish cod fishery between 1920 and 1940 have been commented upon. It is stated that the yield of the cod fishery in our inner waters was very low in the years 1934—38, and that the comparatively small amounts of young cod were caught during the fishing experiments of the Biological Station during the same years.

It has been shown that the development of the fishery during the time between 1920 and 1940 in certain respects has been unfavourable to the stock of cod: (1) there has been a very intense development of the pound-net and eel-weel fisheries, by which many small cod below the minimum size-limit are caught and not liberated again in a state so as to be fit to survive; (2) the preparation of fillet has led to rapidly increasing demands for small cod immediately above the minimum size, which undoubtedly damages the stock in altering the ratio between the small, young cod and the bigger and older cod in the catches. The fishery for waste fish in the form in which it has been pursued to the present date seems to have hurt the stock of cod to no considerable degree.

The decrease both in the size of the cod population and in the yield of the cod fishery about the middle of the thirties is probably due partly to a series of rather poor brood years, partly to the increased inroad made by the fishery on the stock of cod, more particularly on the small cod.

There is hardly any doubt that the cod fishery is now so extensive, that in periods with small occurrences of fry the stock is fished far beyond its power of maintaining its size. Greater attention should therefore in future be paid to the protection of the stock of cod.

The minimum size-limit of 275 mm. for cod, fixed in the Fisheries Act of 1931 is undoubtedly too low, and the provisional raising to 310 mm., enacted by decrees during recent years, should no doubt be made permanent, and examinations should be made into the adequacy and practicability of raising the minimum size-limit another 1 or 2 cm.

It is further desirable that in the emptying of pound-nets and eel-weels the greatest possible care should be taken to liberate the undersized cod caught in the gears in a state so as to be fit to survive.

It remains to be said that it would undoubtedly mean a better utilization of our stock of cod if the cod used for the preparation of fillet were chosen among somewhat bigger fish than is the case at present.

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